NIST GCR 98-734

Hurricane Fran in North Carolina

September 5-6, 1996

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ABSTRACT

This report describes the surface wind speeds and structural damage caused by Hurricane Fran during its passage across North Carolina and Virginia on 5-6 September, 1996. Fran was a category 3 hurricane on the Saffir-Simpson scale, and estimated maximum sustained wind speeds were approximately 36 m/s at Kure Beach, NC, directly north of Cape Fear, the point of landfall. Gust speeds of up to 48 m/s were registered by the C-MAN station at Frying Pan Shoals, located approximately 60 km south-southeast of Cape Fear. Wind damage was extensive over the eastern sections of North Carolina and was caused primarily by falling trees. However, when the probable maximum wind speeds in Hurricane Fran are compared with 50-yr MRI speeds listed in performance-based design standards such as ANSI A58.1 or ASCE 7, it is clear that Fran was substantially less than a design event. There were 36 fatalities in Hurricane Fran, 23 of them in North Carolina. Approximately 4,000 power poles were snapped off in North Carolina and 1,600 km of electrical distribution lines were down. The resulting outages affected more than 2 million customers in South Carolina, North Carolina and Virginia. In terms of losses, North Carolina suffered approximately \$5 billion in damages, making Fran one of the more destructive hurricanes in recent years. Hurricane Fran caused extensive flooding in North Carolina, Virginia, West Virginia, Maryland, Pennsylvania and Ohio. Damage in Virginia and adjacent states was due in large part to local flooding rather than to the direct effects of wind.

Key words: building technology; codes and standards; hurricanes; natural disasters; structural engineering; wind damage; wind engineering; wind loads

DISCLAIMER

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LIST OF ACRONYMS

ANSI	American National Standards Institute, Inc.
ASCE	American Society of Civil Engineers
ASOS	Automated Surface Observing System
C-MAN	Coastal Marine Automated Network
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
HRD	Hurricane Research Division
LDT	Local Daylight Time
MRI	Mean Recurrence Interval
NCDC	National Climatic Data Center
NDBC	National Data Buoy Center
NESDIS	National Environmental Satellite, Data and Information Service
NFIP	National Flood Insurance Program
NHC	National Hurricane Center
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
UTC	Universal Coordinated Time

EXECUTIVE SUMMARY

Hurricane Fran was a category 3 hurricane on the Saffir/Simpson Hurricane Scale that made landfall near Cape Fear, North Carolina, at approximately 0030 UTC on 6 September, 1996 (2030 EDT on 5 September). Fran caused 36 deaths, 23 of them in North Carolina, and resulted in serious flooding as far north as Pennsylvania and Ohio. Damages have been put at more than $5 billion, making Fran one of the more destructive hurricanes in recent years. The strongest winds occurred along the North Carolina coast from Cape Fear to Cape Lookout, but damaging winds persisted inland as far as the Raleigh-Durham area, a distance of approximately 250 km. Maximum sustained wind speeds are estimated to have reached 35.8 m/s along the North Carolina coast at Kure Beach. However, most of the structural damage in this area was caused by a combination of wind, storm surge, and wave attack. With regard to storm surge, it was determined that storm surge elevations exceeded the National Flood Insurance Program (NFIP) base flood elevations from Kure Beach to North Topsail Beach along approximately 80 km of coastline. The recorded maximum high water, assumed to include wave effects, was 4.7 m above mean sea level at Kure Beach. The maximum storm surge elevation, as measured inside a structure without wave effects, was 3.6 m above mean sea level at Figure 8 Island. Directly inland from the coast the estimated maximum sustained wind speed at the Wilmington International Airport ASOS was 30.7 m/s, and the intensity of wind damage was far less severe than the damage observed in the adjacent coastal area.

Because the wind speeds in Hurricane Fran during its overland travel were relatively low, most anemometer sites survived to produce useful wind speed data. In addition, the presence of data buoys and C-MAN stations operated by the National Data Buoy Center (NDBC) produced detailed and highly reliable data on wind speed, wind direction, surface pressure, and wave height. Additionally, ASOS stations along the hurricane track produced detailed records of wind speed and direction. Unfortunately, not all of these stations continued to function throughout the storm when commercial power failed. These sources of wind data were augmented by NWS and FAA stations located along the over-land segment of the storm track.

Design wind speeds associated with or implied by the North Carolina State Building Code were originally based on the wind speed distribution map of ANSI A58.1-1972. Unfortunately, a direct relationship between recommended design wind speeds from performance-based standards such as ANSI A58.1 and the prescriptive-based requirements found in most building codes covering light wood-frame construction usually does not exist. An additional complication can be the fact that building stocks reflect the accumulated influence of past code provisions that may no longer apply or that have been revised substantially over the years. For coastal North Carolina, the design wind speed indicated by ANSI A58.1 is 49.2 m/s. The design wind speed reduces to 47.7 m/s over Wilmington with a further inland reduction to 31.3 m/s to the west of Raleigh. These design speeds correspond to an annual probability of 0.02 of being equalled or exceeded. Put another way, they correspond to a mean recurrence interval (MRI) of 50 years. Comparing the recommended design speeds with the probable maximum sustained speeds in Hurricane Fran, it can be seen that Fran was substantially less than a design event with fairly

modest wind speeds during and following landfall. Nevertheless, the total damage in excess of $5 billion makes Fran one of the more destructive hurricanes in recent years.

1.0 INTRODUCTION

Hurricane Fran was a category 3 hurricane on the Saffir/Simpson Hurricane Scale (1974) that made landfall near Cape Fear, North Carolina, at approximately 0030 UTC on 6 September, 1996 (2030 EDT on 5 September). Hurricane Fran caused 36 deaths, 23 of them in North Carolina, and resulted in serious flooding as far north as Pennsylvania and Ohio. Damages have been put at more than $5 billion, making Fran one of the more destructive hurricanes in recent years. The strongest winds occurred along the North Carolina coast from Cape Fear to Cape Lookout, but damaging winds persisted inland as far as the Raleigh-Durham area, a distance of approximately 250 km. Maximum sustained wind speeds are estimated to have reached 35.8 m/s along the North Carolina coast. However, most of the structural damage in this area was caused by a combination of wind, storm surge, and wave attack. Directly inland from the coast, wind damage was far less severe.

This report presents a summary of the meteorological aspects of Hurricane Fran, tabulations of observed wind speeds, descriptions of the structural damage, and comparisons between probable maximum wind speeds and the design wind speeds required by contemporary performance-based design standards such as ASCE 7-95. All times referenced in this report are in Universal Coordinated Time (UTC). To obtain local (eastern) daylight time, subtract 4 hours from the indicated time (EDT = UTC - 4). Unless noted otherwise, wind speeds are sustained speeds averaged over a period of one minute.

2.0 METEOROLOGICAL ASPECTS OF HURRICANE FRAN

Hurricane Fran had its origin in a tropical wave off the west coast of Africa on 22 August, 1996, and became a tropical depression on the following day. This tropical depression moved westward over the next four days and became Tropical Storm Fran at 0000 UTC on 27 August while still east of the Lesser Antilles. Fran attained hurricane strength at 0000 UTC on 29 August and again on 31 August after being affected by the circulation of Hurricane Edouard located to the west and north. By 4 September, Hurricane Fran was located north of the Bahamas, moving to the northwest at approximately 18 km/h. At 0000 UTC on 5 September, Fran was located approximately 600 km south-southeast of Cape Fear, North Carolina, with maximum sustained winds of about 54 m/s and a central pressure of 94.6 kPa. At the time of landfall some 24 hours later, Hurricane Fran was moving northward with a forward speed of approximately 28 km/h, the central pressure had increased to 95.4 kPa, and the maximum sustained speeds were estimated at 51 m/s. Landfall occurred near Cape Fear, North Carolina, at approximately 0030 UTC on 6 September (2030 EDT on 5 September).

Over the next 24 hours Fran moved across North Carolina and Virginia, weakening to a tropical storm and tropical depression prior to moving across West Virginia and western Pennsylvania. Heavy rainfall was recorded along the storm track, producing serious flooding in North Carolina, Virginia, West Virginia, Maryland, Pennsylvania and Ohio. This system became extratropical at about 0000 UTC on 9 September while centered over southern Ontario,

and was absorbed into a frontal system the following day. Hurricane Fran's storm track for the period 23 August to 8 September, 1996, is shown in Figure 1. Table 1 lists the minimum pressures and maximum sustained speeds, as estimated by the National Hurricane Center (NHC), along the storm track approaching and following landfall. For a more detailed description of the storm track, see Mayfield (1996). Figure 2 shows a GOES East infrared image taken at 0115 UTC 6 September, 1996, shortly following landfall.

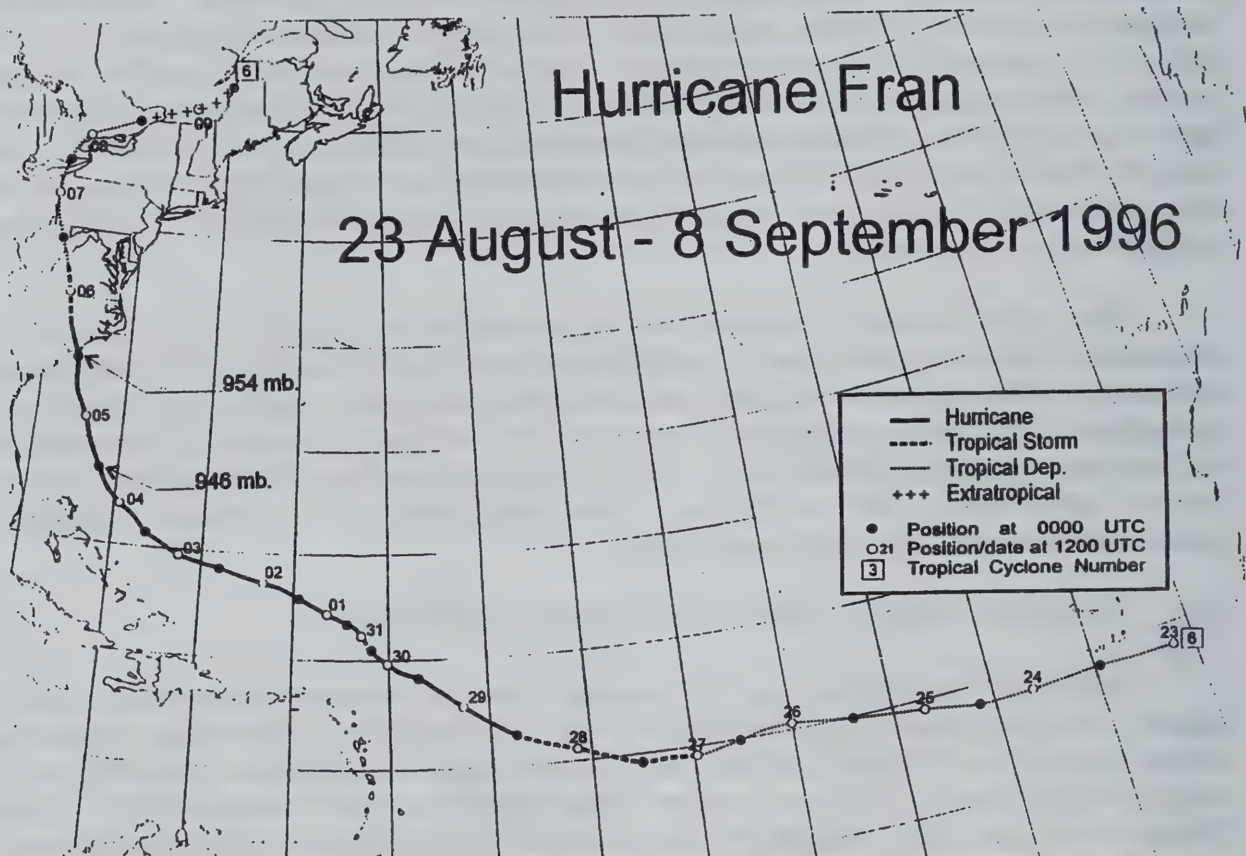

Figure 1. Hurricane Fran's Storm Track for the Period 23 August to 8 September, 1996 (Source: NOAA/NHC).

3.0 SOURCES OF WIND SPEED DATA

Because the wind speeds in Hurricane Fran during its overland travel were relatively low, most anemometer sites survived to produce useful wind speed data. In addition, the presence of data buoys and C-MAN stations operated by the National Data Buoy Center (NDBC) produced detailed and highly reliable data on wind speed, wind direction, surface pressure, and wave height. Additionally, ASOS stations along the hurricane track produced detailed records of wind speed and direction. Unfortunately, not all of these stations continued to function throughout the storm when commercial power failed. These sources of wind data were augmented by NWS and FAA stations located along the over-land segment of the storm track.

Table 1. Estimated Minimum Pressures and Maximum Wind Speeds Along Storm Track Approaching and Following Landfall (Mayfield 1996).

Date & Time (UTC)		Position Lat (°N)	Position Lon (°W)	Pressure (kPa)	Sustained Speed (m/s)
4 September, 1996					
0000	*	25.7	73.1	96.1	48.9
0600		26.4	73.9	95.3	51.4
1200		27.0	74.7	95.6	54.0
1800		27.7	75.5	95.2	54.0
5 September					
0000		28.6	76.1	94.6	54.0
0600		29.8	76.7	95.2	54.0
1200		31.0	77.2	95.4	51.4
1800		32.3	77.8	95.2	51.4
6 September					
0000		33.7	78.0	95.4	51.4
0600		35.2	78.7	97.0	33.4
1200	**	36.7	79.0	98.5	20.6
1800	***	38.0	79.4	99.5	15.4
7 September					
0000		39.2	79.9	100.0	15.4
0600		40.4	80.4	100.1	15.4

Notes:
- * Hurricane
- ** Tropical Storm
- *** Tropical Depression

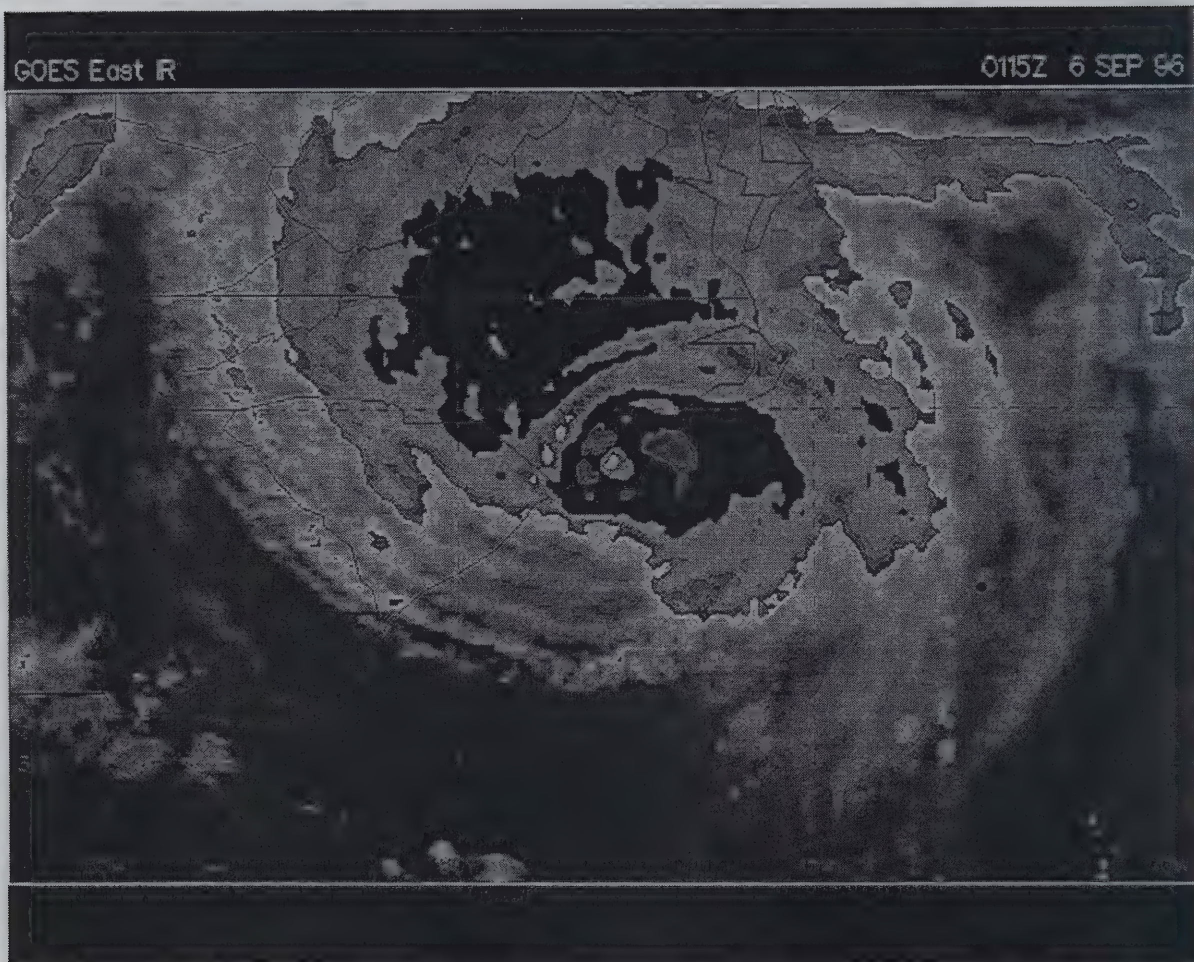

Figure 2. GOES East Infrared Image at 0115 UTC 6 September, 1996 (Source: NOAA/NESDIS).

In the several months following Hurricane Fran, various sources of data became available, including data sets of the National Climatic Data Center (NCDC) and the NDBC archives noted above. Additionally, local NWS offices provided records, including ASOS records, when such information was available. These data are summarized in Table A-1 of Appendix A. Unless noted otherwise, the mean wind speeds listed in Table A-1 are based on an averaging time of 1 minute. Mean wind speeds obtained from C-MAN stations and from ASOS sites are based on a 2-minute averaging time while mean speeds obtained from data buoys are based on an 8-minute averaging time. Gust averaging times depend on the response characteristics of the anemometer/recording system and typically range from 3 to 5 seconds. For C-MAN, ASOS and data buoy stations, the gust averaging time is established at 5 seconds.

For certain stations listed in Table A-1, periodic or continuous records of wind speed were available over intervals of several hours, and these wind speed records are plotted in

Figures A-1 to A-27 of Appendix A. In each case, the data are "raw" data, uncorrected for anemometer height, surface roughness, or for wind speed averaging time.

4.0 WIND SPEED ADJUSTMENTS FOR NON-STANDARD EXPOSURES

As noted previously, the wind speeds listed in Table A-1 and plotted (as available) in Figures A-1 to A-27 in Appendix A are "raw" data and have not been adjusted for standard conditions. As used in this report, standard conditions are taken to mean a wind exposure in flat, open terrain with a surface roughness length of Z_o = 0.03 m and an anemometer height of 10 m. For those stations having an over-water exposure, the surface roughness length is dependent upon wave height. Wind speed adjustments of this nature have become a routine part of the post-disaster assessment of surface wind speeds (Powell et al. 1996, Marshall and Schroeder, 1997). In Table B-1 of Appendix B, wind speeds for selected sites (listed in Table A-1 of Appendix A) have been adjusted to standard conditions. These adjustments were carried out using conventional models of the lower atmospheric boundary-layer (Simiu and Scanlan 1995, ESDU 1995). In each case, the procedure consisted of the following steps:

- o Assume an hourly mean reference wind speed for the selected surface roughness length (over-land or over-water).
- o Assess the fetch upwind of the site by surface roughness length, longitudinal extent, and number of changes in surface roughness length.
- o Calculate the wind speed at the site for the actual anemometer height and wind speed averaging time.
- o Adjust the assumed hourly mean reference speed so that the calculated wind speed at the site matches the corresponding observed speed.
- o Calculate a gust speed consistent with the actual anemometer height, instrument response time and upwind exposure.
- o Compare this calculated gust speed with the observed peak gust. Large differences may suggest a reassessment of the upwind exposure.
- o Calculate the corresponding sustained wind speed (one-minute average) at a height of 10 m for the selected surface roughness length (over-land or over-water).

5.0 PROBABLE MAXIMUM SURFACE WIND SPEEDS

Results of the wind speed adjustments to standard conditions for selected anemometer sites affected by Hurricane Fran are summarized in Table 2. These wind speeds correspond to maximum sustained speeds (1-minute average) at a height of 10 m over an open-water exposure or over flat, open country (z_o = 0.03 m).

Table 2. Adjusted Sustained Speeds at 10 m for Selected Anemometer Sites in Hurricane Fran.

Station Name	Exposure	Sustained Speed (m/s)
Folly Island (FBIS1)	water	12.9
Frying Pan Shoals (FPSN7)	water	36.2
Kure Beach	water	35.8
Wilmington (ILM)	land	30.7
North Topsail Beach	water	33.6
Cape Lookout (CLKN7)	water	30.4
New River MCAS (KNCA)	land	32.0
Cherry Point MCAS (KNKT)	land	28.1
Diamond Shoals (DSLN7)	water	26.7
Duck Pier (DUCN7)	water	20.5
Chesapeake LS (CHLV2)	water	18.6
Thomas Point (TPLM2)	water	16.2

Note: Sustained speeds are averaged over one minute.

From the wind speeds listed in Table 2 it can be seen that the highest estimated sustained speed at 10 m above water was 36.2 m/s at Frying Pan Shoals C-MAN station. At the approximate time of landfall, the corresponding speed at Kure Beach was 35.8 m/s. Further to the north and inland at the Wilmington International Airport ASOS site, the estimated maximum sustained speed at a height of 10 m was 30.7 m/s. Other estimated maximum sustained speeds are 33.6 m/s at North Topsail Beach, 32.0 m/s at the MCAS New River ASOS, and 28.1 m/s at the MCAS Cherry Point ASOS. At the Cape Lookout C-MAN station the estimated maximum sustained speed at 10 m was 30.4 m/s. For additional information on the surface wind field, see Houston and Powell (1997).

6.0 SUMMARY OF WIND DAMAGE

Although Hurricane Fran covered a wide area involving several states, the intensity of damage was moderate when compared with damage intensities associated with other recent landfalling hurricanes. The exception is the coastal area from Cape Fear to Cape Lookout in North Carolina where storm surge and superimposed waves caused severe dune and beach erosion, local scour and structural damage. Beyond the coastal areas of North Carolina the primary cause of structural damage was falling trees. The following sections of this report provide descriptions for four categories of damage/losses.

6.1 Coastal Wind, Surge and Wave Damage

In the days following landfall of Hurricane Fran, the Federal Emergency Management Agency (FEMA) dispatched a building performance assessment team to North Carolina to assess the effects of coastal winds, storm surge and wave action on beaches, dunes and constructed facilities in the coastal area extending from Cape Fear northeast to Cape Lookout, a distance of approximately 150 km. Findings from this study, some of which are summarized in the following paragraphs, are presented in Building Performance Assessment Report 290 (FEMA 1997).

With regard to storm surge, it was determined that storm surge elevations exceeded the National Flood Insurance Program (NFIP) base flood elevations from Kure Beach to North Topsail Beach along approximately 80 km of coastline. The recorded maximum high water, assumed to include wave effects, was 4.7 m above mean sea level at Kure Beach. The maximum storm surge elevation, as measured inside a structure without wave effects, was 3.6 m above mean sea level at Figure 8 Island.

In many locations, particularly from Topsail Beach to North Topsail Beach, localized frontal dunes were eroded and the beach profile was lowered by as much as 1 m. Beach erosion caused by Hurricane Fran was exacerbated by previous dune erosion caused by Hurricane Bertha which made landfall in the same general area some 2 months earlier.

The primary types of buildings in the coastal area consist of one- and two-family wood frame dwellings of one to three stories, elevated on timber piles. In fact, since the 1960's, most houses on the barrier islands of North Carolina have been constructed on timber piles.

The combined effects of beach erosion and scour resulted in the collapse of more than 100 homes founded on shallow pile foundations in the area extending from Topsail Beach to North Topsail Beach. In general, wood-frame structures on elevated pile foundations outperformed all other types of foundations, including masonry piers, solid perimeter masonry walls, and slab-on-grade systems. The lack of sufficient embedment of vertical foundation members for items such as decks, porches, and roof overhangs resulted in the collapse of several hundred of these building extensions. Typical damage to wood-frame structures in the affected coastal area can be seen in Figures 3 and 4.

Figure 3. Surge and Wave Damage, North Carolina Coastal Area (Source: FEMA).

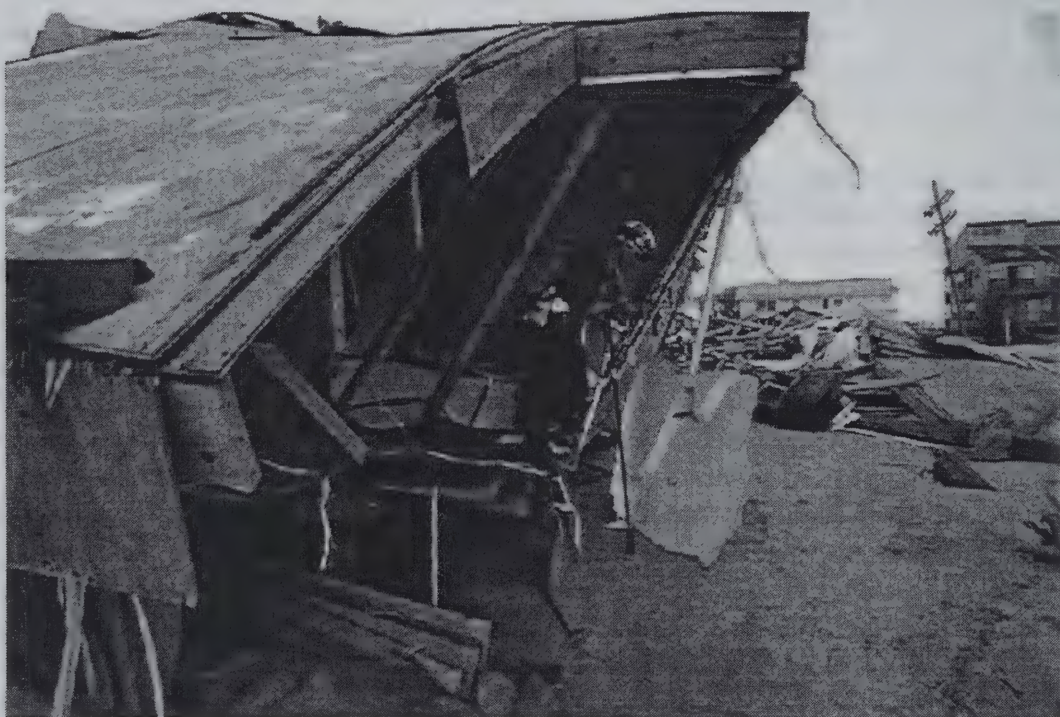

Figure 4. Damaged Manufactured Home, North Topsail Beach (Source: FEMA).

According to the FEMA field study, manufactured home foundation and anchoring systems performed poorly with a failure rate of approximately 50 percent of manufactured homes and recreational vehicles (RV's) observed at Surf City and North Topsail Beach. Apparently the preferred foundation system (piers) consisted of stacked concrete masonry units without mortar, while the anchorage systems generally depended upon metal strapping attached to auger-type soil anchors equipped with 102 mm helix plates and a 610 mm shaft length. Observed failure mechanisms were the undercutting of pier footings due to scour, pull-out of the shallow soil anchors by wind and wave forces, or these two mechanisms combined.

Previous work has established very clearly the inadequacy of the above-described anchoring system (Marshall 1994). That such a system was widely used in a coastal area is indeed disturbing. Given existing criteria for scour protection and recent performance-based criteria for the design of manufactured home foundation and anchoring systems (Marshall and Yokel 1995), the expectation should be for far better performance in future extreme events.

6.2 Inland Structural Damage

Figure 5. First Baptist Church, Market Street, Wilmington.

While numerous occurrences of significant structural damage were observed inland from the coastal area of New Hanover, Pender and Onslow Counties, the general level of structural damage in these areas was moderate when compared with inland damage in other recent landfalling hurricanes. Perhaps the most spectacular structural failure in the Wilmington area was that of the east spire of the First Baptist Church on Market Street, as shown in Figure 5. The view is to the east-northeast, the approximate direction of the wind at the time the east spire failed.

A recently-completed light-aircraft hanger located near the south boundary of Wilmington International Airport is shown in Figure 6. The view is to the north-northwest. Another view of the opposite side of the failed hangar is shown in Figure 7 looking to the southwest. Maximum sustained wind speeds in this area were approximately 31 m/s. At the time of failure the winds were from the east, and it is likely that failure initiated in the end-bay purlins (subjected to combined axial thrust and uplift forces) or in the purlin-end wall connections. Loads on these purlins and their connections probably were increased with failure of the door near the windward face of the hanger as can be seen in Figure 6.

Figure 6. Aircraft Hangar, Wilmington International Airport (view to northwest).

Figure 7. Aircraft Hangar, Wilmington International Airport (view to southwest).

Figure 8. Gasoline Pump Canopy, US 421 Northwest of Wilmington.

Typical of numerous failures of light commercial construction in the Wilmington area is the gasoline pump canopy shown in Figure 8. However, this particular structure suffered from severe internal corrosion of the square-tube supporting columns as could be observed at the failure points directly above the concrete service island. This site is located 25 km to the northwest of Wilmington along US 421.

The most common damage mechanism observed in the Wilmington area as well as in the Raleigh-Durham area some 250 km inland to the northwest is shown in Figure 9. Falling trees took a heavy toll on most forms of construction, single-family dwellings in particular. The fact that Hurricane Bertha brought heavy rainfall to the area about two months prior to Fran may have increased the potential for uprooting trees in Hurricane Fran.

Figure 9. House Damage by Fallen Trees Along US 17 Northeast of Wilmington.

6.3 Damage to Power Distribution Systems

According to FEMA, more than 2,000,000 customers in South Carolina, North Carolina and Virginia were left without electric service immediately following Hurricane Fran. Of these outages, 1.7 million were reported to be in North Carolina and approximately 400,000 were reported in Virginia. Significant disruptions of electric service were experienced in the

immediate Wilmington area (New Hanover County), and to the northeast along US 17 in Pender and Onslow Counties. In Carolina Power and Light's (CP&L) eastern region, more than 2,300 power poles were broken and approximately 500 miles of distribution lines were down. It was reported that more than 4,000 power poles failed statewide, and that approximately 1,600 km of distribution lines were down (Wilmington Morning Star, 09/10/96).

As of September 8, 1996, FEMA reported the following situation with regard to electrical service in the affected areas: "The number of customers without power is slightly over one million. Virginia Power has made substantial progress in restoring service to the thousands of customers left without power. The total number of Virginia customers without power is now about 181,000. The total number for North Carolina outages is about 729,000 customers. CP&L reports that 383,000 customers are still without electric power, down from a peak of 670,000. Duke Power, in North Carolina, reported yesterday that 120,000 customers were still without power. At the peak outage, Duke Power reported approximately 330,000 customers were without power. North Carolina Power reported 4,000 customers without service in the Roanoke Valley."

The CP&L Brunswick nuclear power plant, located approximately 40 km southwest of Wilmington, was shut down prior to hurricane landfall and suffered some wind damage to the roof membrane on the generator building. Eighteen of 28 rural cooperatives operating in the affected area reported damage to power distribution systems. On September 13, one week after hurricane landfall, FEMA reported only about 77,000 households in isolated pockets of North Carolina remained without electric power. Immediately following landfall, it was estimated that 96 percent of the state was without electric service.

6.4 Other Wind Damage

Damages to homes and businesses in North Carolina were estimated at approximately $2.3 billion, and damage to roads, bridges, utilities, debris removal were estimated at $1.1 billion. Agricultural losses in the state were put at over $700 million with forestry losses estimated at an additional $1 billion. Thus the total damage due to Hurricane Fran in North Carolina was put at approximately $5 billion. Financial assistance provided to selected counties in North Carolina by number of cases and dollar amount is summarized in Table 3 for four categories of assistance. These figures reflect both the wind intensity and the wind hazard potential represented by heavily developed and populated counties. It is interesting to note that while New Hanover County (Wilmington) was most directly affected by the strong onshore winds in Hurricane Fran, extensive losses occurred as far inland as Wake County (Raleigh), approximately 250 km to the north-northwest. As noted previously, most of the wind-caused damage in Wilmington as well as in the Raleigh-Durham area appeared to be the direct result of fallen trees.

Table 3. Financial Assistance Provided to Selected Counties in North Carolina. (Number of cases and dollar amounts by category of assistance)

County	Temporary Housing		Individual & Family Grants		SBA Loans		Public Assistance	
Beaufort	916	$2,167,000	402	$1,326,000	205	$3,053,000	26	$342,000
Bladen	1,114	1,926,000	584	761,000	67	-------	32	490,000
Brunswick	858	1,219,000	245	345,000	92	959,000	67	1,117,000
Carteret	333	663,000	132	296,000	123	5,962,000	44	1,187,000
Columbus	1,572	2,157,000	803	1,195,000	80	964,000	30	413,000
Duplin	1,223	2,109,000	532	1,042,000	174	1,553,000	48	1,473,000
Johnston	713	1,212,000	284	642,000	232	2,940,000	93	3,015,000
Lenoir	768	1,393,000	383	1,333,000	96	1,774,000	43	2,082,000
New Hanover	2,984	4,091,000	1,991	3,934,000	959	28,944,000	104	23,159,000
Onslow	2,020	3,249,000	713	1,913,000	440	10,859,000	127	8,228,000
Pender	1,593	2,791,000	588	1,733,000	402	6,728,000	55	4,086,000
Robeson	942	1,140,000	371	523,000	81	644,000	39	1,077,000
Sampson	818	1,004,000	256	416,000	116	1,304,000	33	1,001,000
Wake	2,598	3,807,000	898	1,860,000	1,032	13,135,000	42	11,044,000
Wayne	880	1,421,000	347	1,010,000	152	3,636,000	63	2,685,000

7.0 DESIGN WIND LOAD REQUIREMENTS

Design wind speeds associated with or implied by the North Carolina State Building Code were originally based on the wind speed distribution map of ANSI A58.1-1972. More recently, code revisions have been based on recommended design speeds and other wind load provisions of ASCE 7, the successor to ANSI A58.1. The main purpose in conducting field studies of building performance following extreme events such as Hurricane Fran is to assess the adequacy of wind load design requirements of the applicable building code, the enforcement of those requirements, and the quality of local construction practices. Unfortunately, a direct relationship between recommended design wind speeds (performance-based standards such as ASCE 7) and the prescriptive-based requirements found in most building codes covering light wood-frame construction usually does not exist. An additional complication can be the fact that building stocks reflect the accumulated influence of past code provisions that may no longer apply or that have been substantially revised over the years.

Given this set of circumstances, it generally is the case that comparisons between observed or corrected wind speeds in an actual extreme event such as Hurricane Fran can only be made with recommended design wind speeds listed in performance-based standards such as ASCE 7 or its predecessor ANSI A58.1. And the degree to which the conclusions reached therefrom apply to actual construction is critically dependent upon how well the prescriptive requirements of the local building code reflect those recommended design wind speeds. With this background, wind speeds at selected sites affected by Hurricane Fran are compared with certain recommended design wind speeds in the following paragraph.

Previous to the most recent edition of ASCE Standard 7 (ASCE 7-95), design wind speeds listed in ASCE 7 and in ANSI A58.1 were fastest-mile speeds at a height of 10 m over flat, open country, designated as exposure category C. This speed is averaged over the time required for a mile-long column of air to pass a fixed point and corresponds exactly to the one-minute sustained wind speed at a speed of 26.8 m/s (60 mph). Although these two measures of wind speed (sustained and fastest-mile) diverge above 26.8 m/s, they can be used interchangeably in modestly high speeds without significant error. For coastal North Carolina, the design wind speed indicated by ANSI A58.1 is 49.2 m/s, reducing to 47.7 m/s over Wilmington, and with a further inland reduction to 31.3 m/s to the west of Raleigh. These design speeds correspond to an annual probability of 0.02 of being equalled or exceeded. Put another way, they correspond to a mean recurrence interval (MRI) of 50 years. Comparing the recommended design speeds with those speeds listed in Table 2, it can be seen that Hurricane Fran was considerably less than a design event with fairly modest wind speeds during and following landfall. Nevertheless, the total damage in excess of $5 billion makes Fran one of the more destructive hurricanes in recent years.

8.0 MAJOR FINDINGS AND RECOMMENDATIONS

8.1 General

This report has described the development, translation, landfall and dissipation of Hurricane Fran over the period 22 August to 10 September, 1996. Sources of wind speed observations have been identified and described. For certain anemometer sites affected by Hurricane Fran, wind speed observations have been adjusted for standard conditions of exposure, defined here as a height of 10 m above flat, open country with a typical surface roughness length of $z_0 = 0.03$ m, or an over-water exposure with z_0 dependent upon wave height. These adjusted speeds have been compared with the 50-yr design wind speeds listed in performance-based standards such as ANSI A58.1 and ASCE 7.

Typical structural damage observed in the area of hurricane landfall has been described and documented. And special emphasis has been given to observed building performance in the North Carolina coastal area where the processes of wind, storm surge and wave attack caused dune and beach erosion, scour and direct damage to structures.

8.2 Major Findings

The following major findings are a result of the field study described in this report:

- Total damage to the area affected by Hurricane Fran exceeded $5 billion, making Fran one of the more destructive hurricanes in recent years.

- Immediately after landfall more than 2,000,000 customers in South Carolina, North Carolina and Virginia were without electric power.

- In North Carolina more than 4,000 utility poles were broken, and approximately 1,600 km of electric power distribution lines were down.

- In the North Carolina coastal area extending from Cape Fear in the southwest to Cape Lookout in the northeast, maximum surge heights of 3.6 m were observed. Storm surge elevations exceeded the National Flood Insurance Program (NFIP) base flood elevations from Kure Beach to North Topsail Beach along approximately 80 km of coastline.

- In general, wood-frame structures on elevated pile foundations in the coastal area outperformed all other types of foundations (masonry piers, solid perimeter masonry walls and slab-on-grade).

- Manufactured home foundation and anchoring systems performed poorly in the coastal area. A failure rate of approximately 50 percent of manufactured homes and recreational vehicles (RV's) was observed at Surf City and North Topsail Beach.

- o Maximum sustained winds (averaged over 1 minute) at a height of 10 m ranged from 36.2 m/s at the Frying Pan Shoals C-MAN station to 35.8 m/s at Kure Beach. Inland, the adjusted maximum sustained speed at the Wilmington International Airport ASOS was 30.7 m/s.

- o A comparison of 50-yr design wind speeds contained in performance-based standards such as ANSI A58.1 and ASCE 7 suggest that Hurricane Fran was substantially less than a design event and that the observed extreme wind speeds in the affected area were relatively moderate.

8.3 Recommendations

The following recommendations are offered in view of the fact that Hurricane Fran was substantially less than a design event:

- o The poor performance of manufactured homes observed at Surf City and North Topsail Beach, North Carolina, is not surprising given the types of foundation and anchoring systems used at the time of Hurricane Fran. Criteria for scour protection of piers and performance-based criteria for the design of manufactured home foundation and anchoring systems are available and should be implemented.

- o There is a continuing need to improve the reliability of wind speed observations in extreme wind events. Although the ongoing deployment of ASOS has been most helpful in promoting uniformity of wind speed measurements, the fact remains that these installations are highly vulnerable due to their total dependence on local commercial power, usually the first service to be lost following hurricane landfall.

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10.0 ACKNOWLEDGMENTS

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APPENDIX A

Compilation of Wind Speed and Pressure Records

Table A-1. Summary of Surface Pressures and Wind Speeds in Hurricane Fran (Raw Data - Uncorrected)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
SOUTH CAROLINA:										
Beaufort MCAS (KNBC)	32.49	80.70	05/*	100.74	16.9	26	2	--	9	10
Folly Island (FBIS1)	32.68	79.88	05/1700***	99.76	24	31	2	360	3	10
Charleston City	32.78	79.93	05/1850**	--	29	41	1	--	0	7.6
Charleston (CHS)	32.90	80.04	05/* 05/2330**	100.64 99.80	22.9 27	32.1 36	2	--	13	10
Myrtle Beach (MYR)	33.68	78.93	05/*	--	35	46	1	--	8	--
N. Myrtle Beach (CRE)	33.82	78.72	06/*	--	15.9	23.9	1	--	10	--
McEntire ANG Base (MMT)	33.92	80.80	06/*	100.75	20	29.9	1	--	77	4.6
Columbia (CAE)	33.94	81.12	05/*	100.62	18.1	22.9	2	--	73	10
Shaw AFB (SSC)	33.97	80.47	05/*	100.56	20	27	1	--	74	4.6
Florence (FLO)	34.19	79.73	05/* 06/* 06/0250**	-- -- --	25.1 29.9 30	49.9 42 56	2	--	45	10

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
NORTH CAROLINA:										
Frying Pan Shoals (FPSN7)	33.48	77.58	05/2100***	96.06	79	94	2	79	0	44.2
Southport St. Pilot Office	33.92	78.05	**	--	--	91	--	--	--	--
Holden Beach	33.92	78.26	05/2300**	--	--	60	--	--	--	--
Kure Beach	34.00	77.91	06/0000***	--	57.9	82.1	60	65	--	10
Wrightsville Beach (1W9)	34.18	77.82	--	--	--	--	--	--	3	--
NOAA Ship Whiting	34.21	77.95	05/2135**	95.99	--	--	--	--	--	--
Wilmington (ILM)	34.27	77.91	06/* 05/2349** 06/0049***	99.62 96.14 --	50.9 58 58	75 75 75	2	--	9	10
North Topsail Beach	34.52	77.36	06/0045**	--	65	--	1	90	0	12.2
Cape Lookout (CLKN7)	34.62	76.52	06/0300***	99.69	56	67	2	148	5	10
Atlantic Beach	34.70	76.74	**	--	--	87	--	--	--	--
Duke Marine Lab-Beaufort	34.72	76.67	**	--	--	80	--	--	--	--

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
New River MCAS (KNCA)	34.71	77.44	06/*	100.37	49.9	69.9	2	--	5	10
			06/**	98.20	--	82		--		
			06/0156***	98.25	58	82		90		
Jacksonville AWOS (OAJ)	34.83	77.62	05/*	--	36.9	47	1	--	29	--
Cherry Point MCAS (KNKT)	34.90	76.88	06/*	100.36	37.9	62	2	--	10	10
			06/0255**	99.39	43	66		--		
			06/0244***	--	51	66		118		
Fayetteville (FAY)	34.98	78.88	05/*	--	23.9	37.9	1	58	--	--
			06/0430**	97.16	55	69				
MacKall AAF (HFF)	35.03	79.50	05/*	101.24	11.1	18.1	1	--	115	--
New Bern (EWN)	35.07	77.05	05/*	101.21	20	33	2	--	4	7.9
			06/*	101.03	15	25.1		--		
Fort Bragg (FBG)	35.13	78.93	06/*	99.94	29.9	54	1	--	74	--
			06/0431**	97.23	38	64				
Diamond Shoals (DSLN7)	35.15	75.30	06/0400***	100.66	58	65	2	137	0	46.6
Pope AFB (POB)	35.17	79.02	06/*	99.58	36.9	55	1	--	66	--
			06/0418**	97.76	43	58				
Cape Hatteras (HSE)	35.23	75.62	06/*	101.15	35	47	2	--	3	10
Charlotte (CLT)	35.21	80.95	06/*	100.57	21	26	2	--	234	10
Southern Pines AWOS (SOP)	35.23	79.40	06/*	--	21	40	1	--	141	--

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
Cape Hatteras (HAT)	35.27	75.55	06/*	100.81	35	--	1	--	3	--
Kinston (ISO)	35.33	77.62	05/*	--	20	29.9	1	--	29	--
Seymour-Johnson AFB (GSB)	35.33	77.97	06/*	99.85	52.1	62.9	1	--	33	--
			06/0555**	98.10	55	70				
Pitt-Greenville (PGV)	35.63	77.40	06/*	--	36.9	52.1	1	--	8	--
Hickory (HKY)	35.73	81.38	06/*	100.86	18.1	29.9	1	--	362	--
Rocky Mount (RWI)	35.85	77.90	06/*	--	21	39	2	--	48	7.9
			06/0445**	98.07	17	39				
Raleigh-Durham (RDU)	35.87	78.78	06/*	100.06	42	57.9	2	--	130	10
			06/0453**	97.76	39	69				
Manteo/Dare Co. (MQI)	35.92	75.70	06/*	--	27	39	1	--	4	--
Greensboro (GSO)	36.08	79.95	06/*	100.13	27	42	2	--	276	10
			06/0900**	98.44	30	42				
Winston Salem (INT)	36.13	80.22	06/*	--	20	22	2	--	292	7.9
Duck Pier (DUCN7)	36.18	75.75	06/0900***	100.69	41	47	2	133	0	20.4
Elizabeth City (ECG)	36.26	76.18	06/*	--	37.9	47	2	--	12	10
			06/1255**	100.51	37	48				

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
VIRGINIA:										
Martinsville (MTV)	36.63	80.02	06/*	--	19	28.9	1	--	287	--
Franklin (FKN)	36.70	76.90	06/*	--	22.9	39	1	--	12	--
Danville (DAN)	36.72	79.33	06/* 06/0449**	-- 98.75	34 34	40 46	1	--	175	--
Hillsville (HLX)	36.77	80.82	06/*	--	35.9	42	1	--	834	--
Oceana NAS (KNTU)	36.82	76.03	06/*	100.81	28.9	36.9	2	--	7	10
Norfolk Intl. (ORF)	36.90	76.20	06/*	100.75	26	37.9	2	--	15	10
Chesapeake LS (CHLV2)	36.92	75.72	06/1000***	100.71	40	46	2	124	0	43.3
Norfolk NAS (KNGU)	36.93	76.30	06/* 06/0805**	-- 100.46	28 36	43.9 55	2	--	9	10
Langley AFB (LFI)	37.08	76.37	06/*	--	29.9	42	1	--	3	--
Newport News (PHF)	37.13	76.49	06/*	--	30.9	48	2	--	13	10
Ft. Eustis (FAF)	37.13	76.62	06/*	--	26	36.9	1	--	4	--
Dublin (PSK)	37.13	80.68	06/*	--	21	33	1	--	642	--

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
Petersburg AWOS (PTB)	37.18	77.52	06/*	--	28	39	1	--	59	--
Roanoke (ROA)	37.32	79.97	06/*	100.34	33	43.9	2	--	363	10
			06/0954**	99.47	33	44				
Lynchburg (LYH)	37.33	79.20	06/*	--	18.1	30.9	2	--	295	10
			06/1243**	99.06	18	38				
Farmville (FVX)	37.35	78.43	06/*	--	22	30.9	1	--	125	--
Richmond (RIC)	37.50	77.33	06/*	100.59	32.1	46	2	--	50	10
			06/1141**	100.08	32	46				
Hot Springs (HSP)	37.95	79.83	06/*	--	27	42	1	--	1156	--
			06/1540**	100.24	29	48				
Wallops Island (WAL)	37.93	75.48	06/*	101.22	25.1	34	2	--	14	10
Charlottesville (CHO)	38.13	78.45	06/*	--	20	37.9	2	--	192	7.9
			06/1045**	99.86	22	38				
Shannon Airport (EZF)	38.27	77.45	06/*	--	23.9	34	1	--	26	--
Staunton/Shenandoah (SHD)	38.27	78.90	06/*	--	26	42.9	1	--	366	--
			06/1120**	99.76	25	43				
Quantico MCAF (KNYG)	38.50	77.30	06/*	--	25.1	36.9	2	--	3	10
Ft. Belvoir (DAA)	38.72	77.18	06/*	--	15.9	35	1	--	21	--
Manassas AWOS (HEF)	38.72	77.52	06/*	--	22.0	41	1	--	59	--

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
Washington Nat. (DCA)	38.85	77.03	06/*	--	33	40	2	--	18	7.9
Washington Dulles (IAD)	38.95	77.45	06/*	101.00	25.1	35	2	--	94	10
Leesburg (JYO)	39.08	77.57	06/*	--	18.1	26	1	--	119	--
Winchester (OKV)	39.15	78.15	06/*	--	21	33	1	--	222	--
WEST VIRGINIA:										
Bluefield (BLF)	37.30	81.20	06/*	--	15	22	2	--	873	7.9
Beckley (BKW)	37.78	81.12	06/*	--	15.9	28	2	--	765	10
Lewisburg/Greenbriar (LWB)	37.87	80.40	06/*	--	15	29.9	1	--	702	--
Charleston (CRW)	38.37	81.60	06/*	--	8	19	2	--	299	7.9
Elkins (EKN)	38.88	79.85	07/*	100.81	16.9	25.1	2	--	604	7.9
Martinsburg (MRB)	39.40	77.98	06/*	101.03	20	29.9	2	--	165	7.9
Morgantown (MGW)	39.65	79.92	06/*	--	12	26	1	--	380	--
Wheeling (HLG)	40.18	80.65	06/*	--	18.1	28	1	--	365	--

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
MARYLAND:										
Patuxent River NAS (KNHK)	38.28	76.40	06/*	101.02	26	42	2	--	6	10
Andrews AFB (ADW)	38.82	76.87	06/*	--	25.1	39	1	--	86	--
Thomas Point (TPLM2)	38.90	76.44	06/2000***	100.58	32	38	2	123	0	18
Hagerstown (HGR)	39.70	77.73	06/*	--	22	35	1	--	215	--
PENNSYLVANIA:										
Washington AWOS (AFJ)	40.13	80.28	06/* 07/*	-- --	15 16.9	23.9 23.9	1	--	361	--
Pittsburgh Intl. (PIT)	40.50	80.22	06/*	100.50	18.1	29.9	2	--	358	10
DATA BUOYS:										
41527 (Drifter)	30.63	77.55	05/1000	96.75	22	31	8	350	0	1.3
41529 (Drifter)	31.28	77.30	05/1200	95.55	24	32	8	80	0	1.3
41022 (Olympic S.W.)	31.89	80.96	05/2200***	100.31	No valid wind speed data.			Wave height = 7.7 m.		
41021 (Olympic N.E.)	31.92	80.85	05/1600	100.35	12	15	8	330	0	5

Table A-1 (Cont.)

Station Name	Lat. (N) (deg)	Lon. (W) (deg)	Date Time (UTC)	SLP (kPa)	Avg. Speed (kts)	Gust Speed (kts)	Avg. Time (min)	Dir. (deg)	Sta. Elev. (m)	Anemo. Ht. (m)
41002 (S. Hatteras)	32.27	75.19	05/1700***	100.03	37	50	8	119	0	5
41530 (Drifter)	32.30	76.48	05/2000	98.45	25	32.8	8	150	0	1.3
41004 (Failed 05/1900)	32.5	79.1	05/1900***	98.87	47	63	8	322	0	10

NOTES:

1. Listed date and time correspond to time of mean wind speed observation.
2. (*) indicates data obtained from NCDC Global Summary. Pressures are averaged over the day.
3. (**) indicates data provided by other NOAA sources.
4. (***) indicates data obtained directly from station records.
5. Avg. Time indicates number of minutes over which the mean wind speed was averaged.
6. To convert knots to meters per second, multiply by 0.5144.

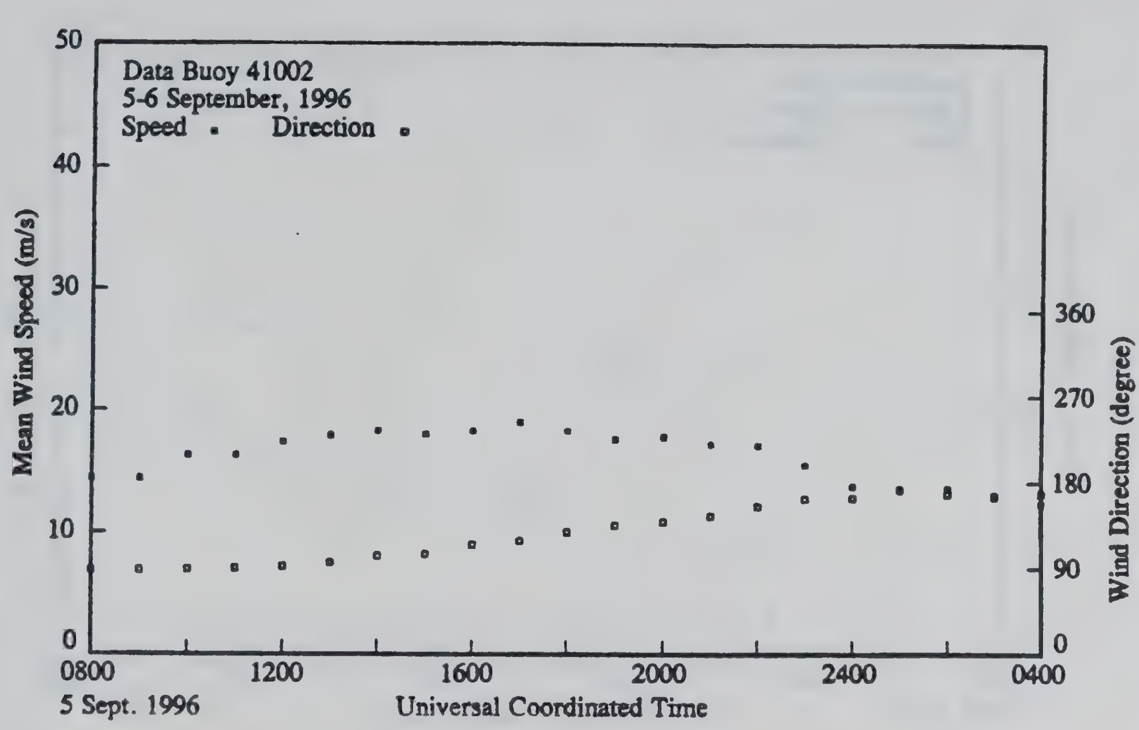

Figure A-1. Record of mean wind speed and direction, Data Buoy 41002.

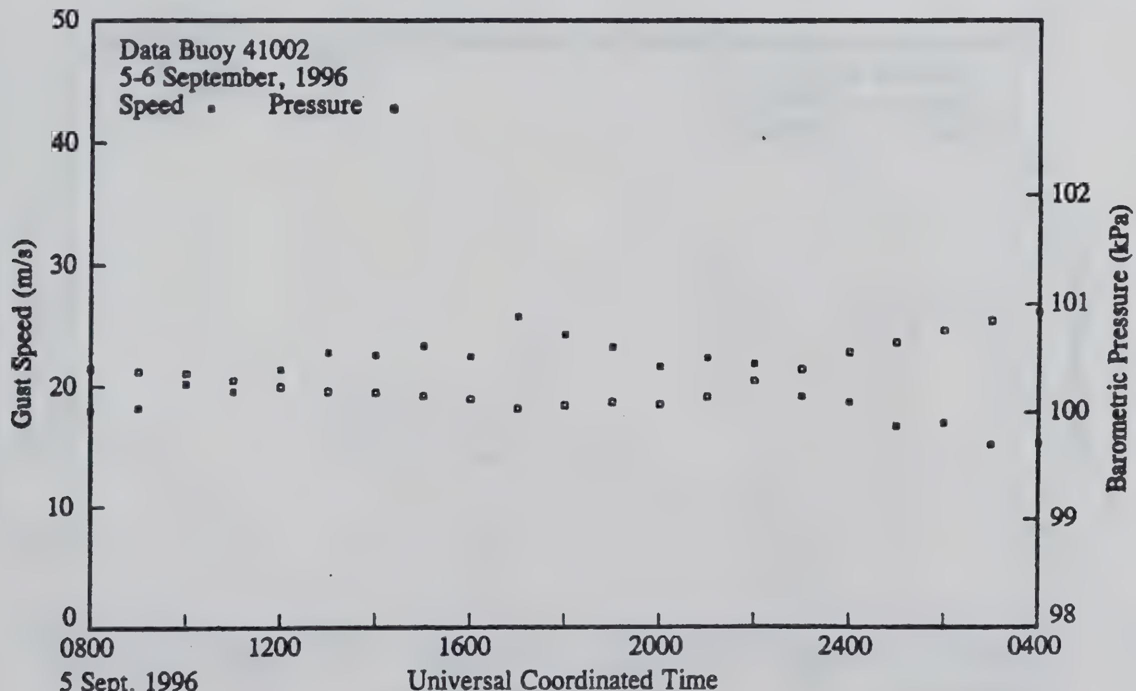

Figure A-2. Record of gust speed and barometric pressure, Data Buoy 41002.

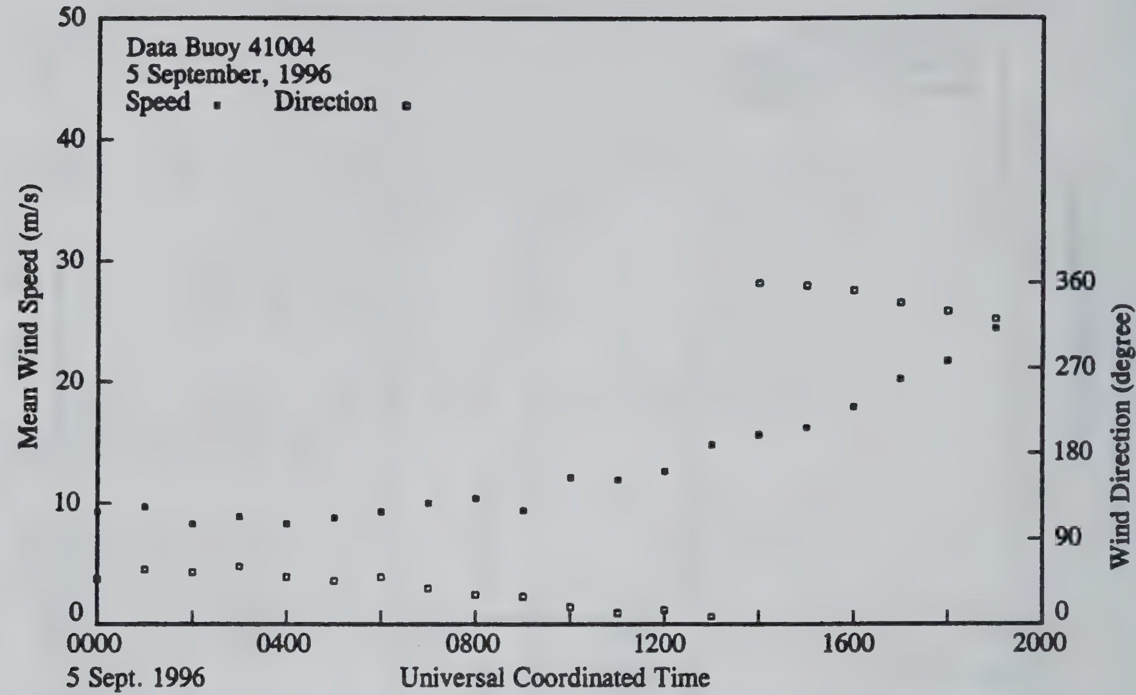

Figure A-3. Record of mean wind speed and direction, Data Buoy 41004.

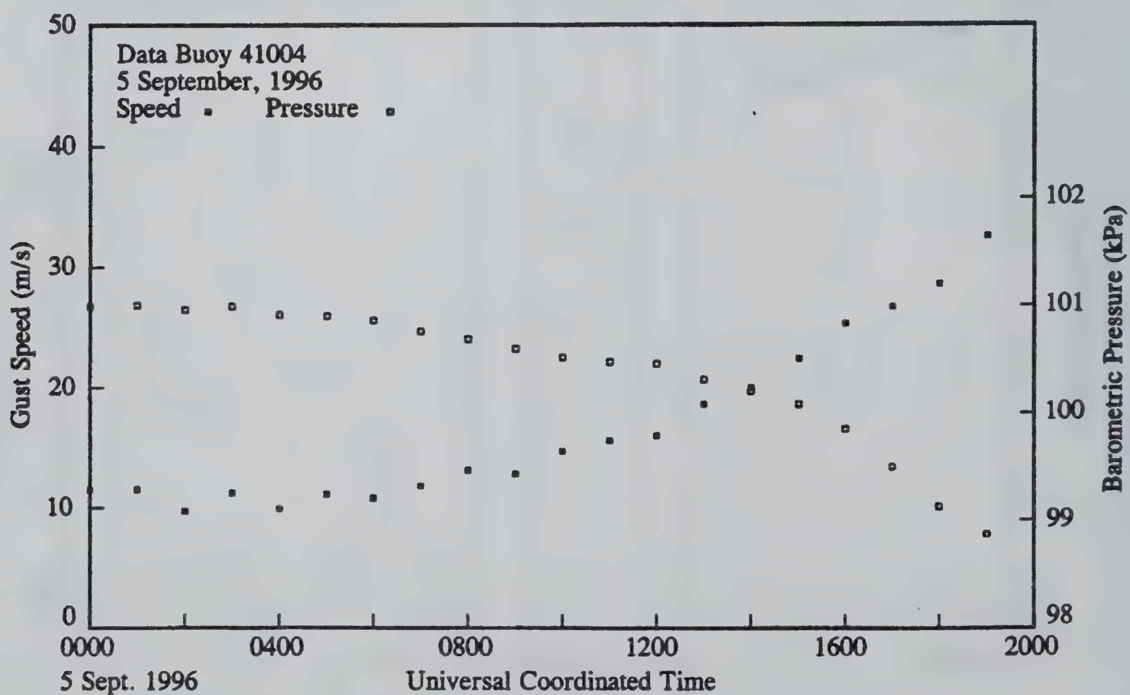

Figure A-4. Record of gust speed and barometric pressure, Data Buoy 41004.

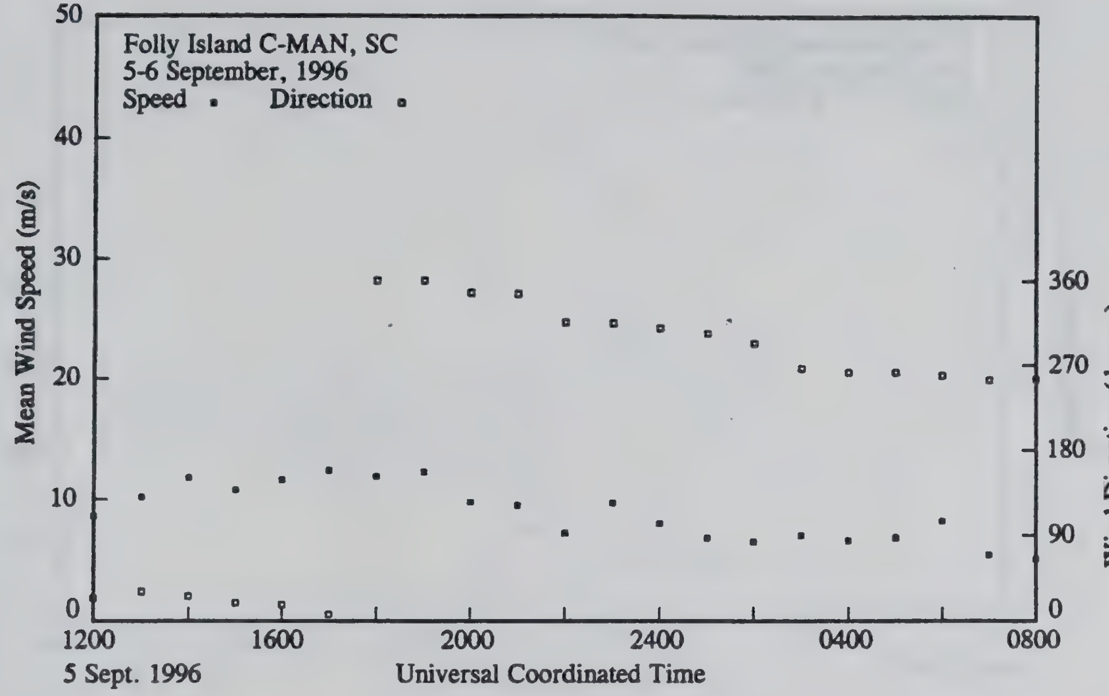

Figure A-5. Record of mean wind speed and direction, Folly Island C-MAN, SC.

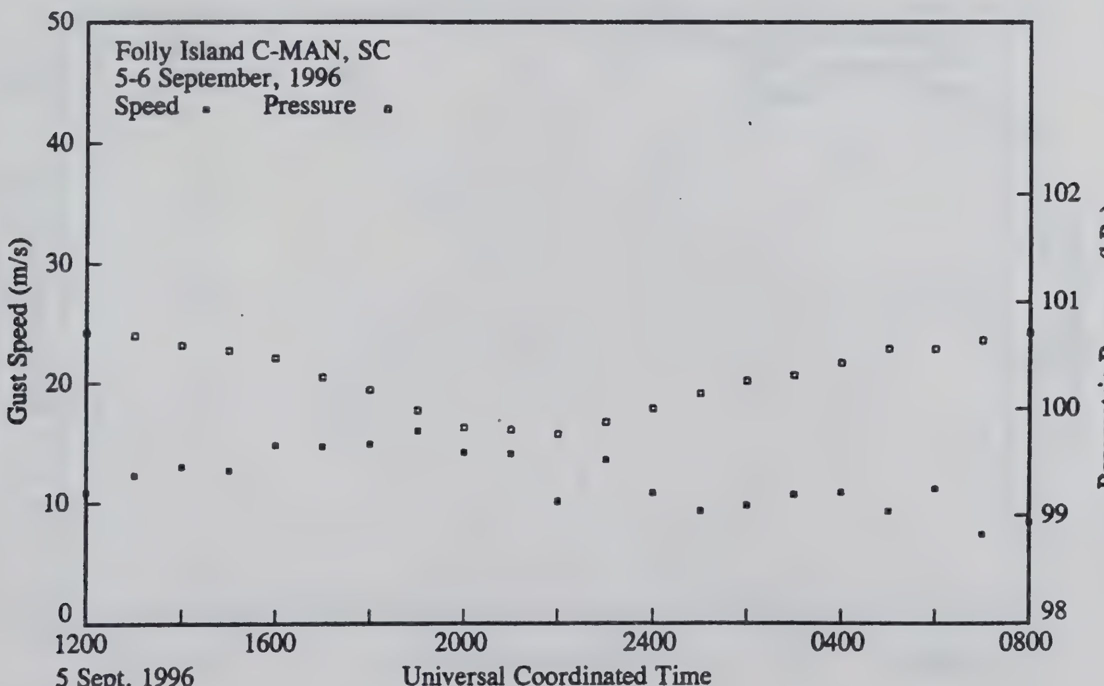

Figure A-6. Record of gust speed and barometric pressure, Folly Island C-MAN, SC.

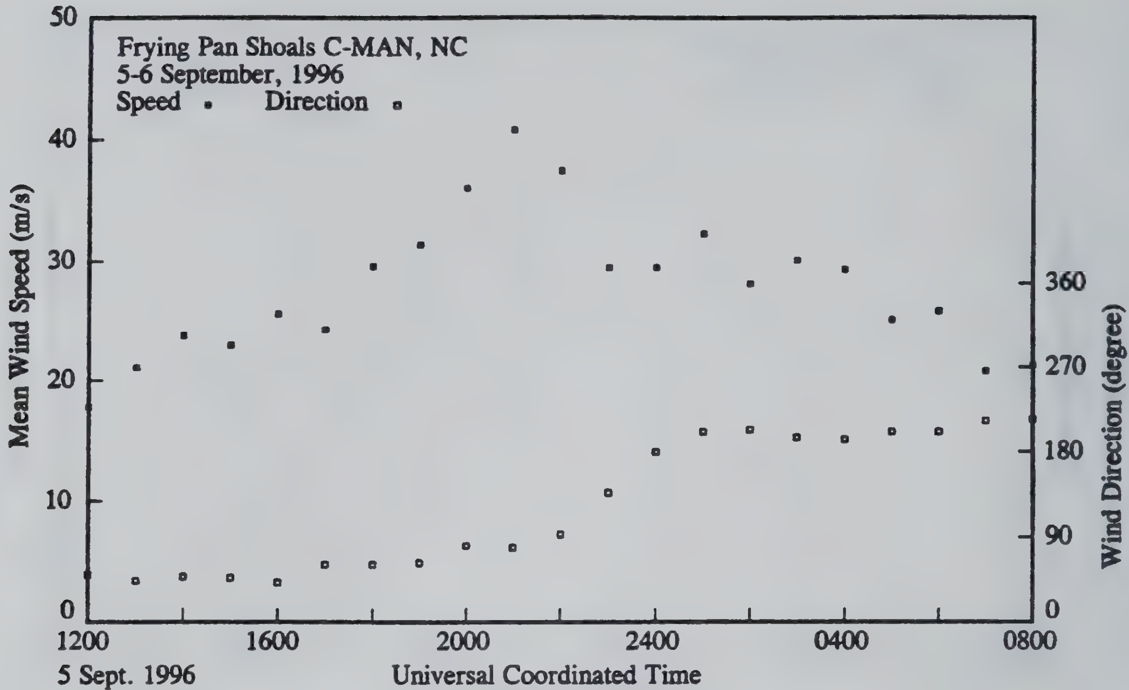

Figure A-7. Record of mean wind speed and direction, Frying Pan Shoals C-MAN, NC.

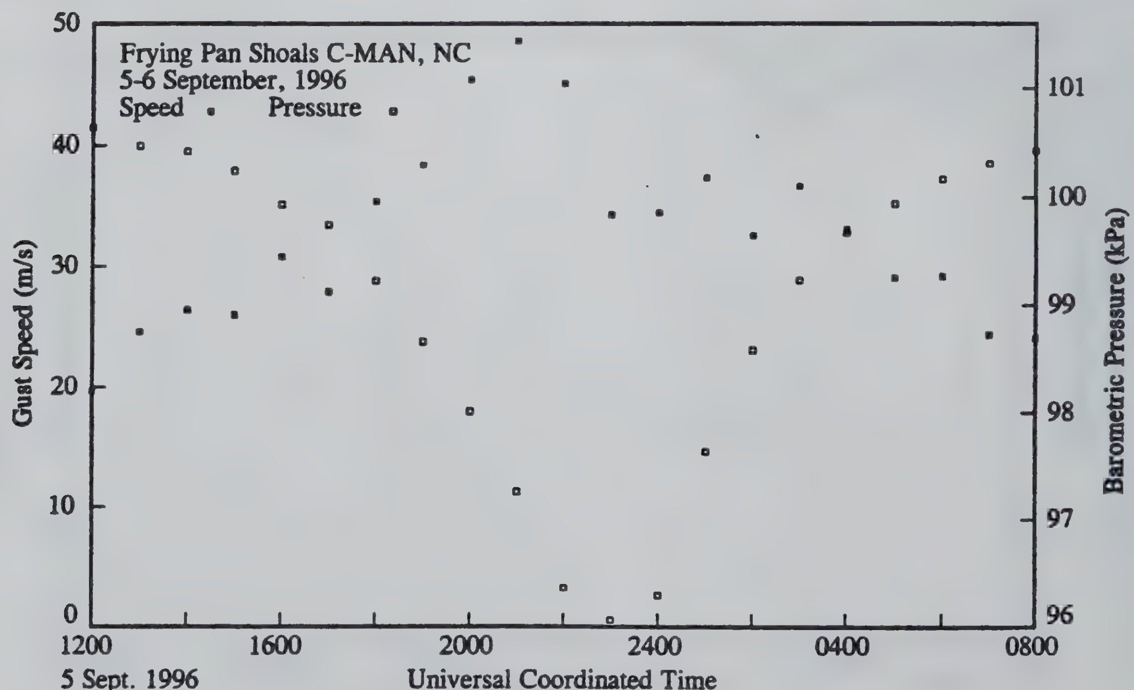

Figure A-8. Record of gust speed and barometric pressure, Frying Pan Shoals C-MAN, NC.

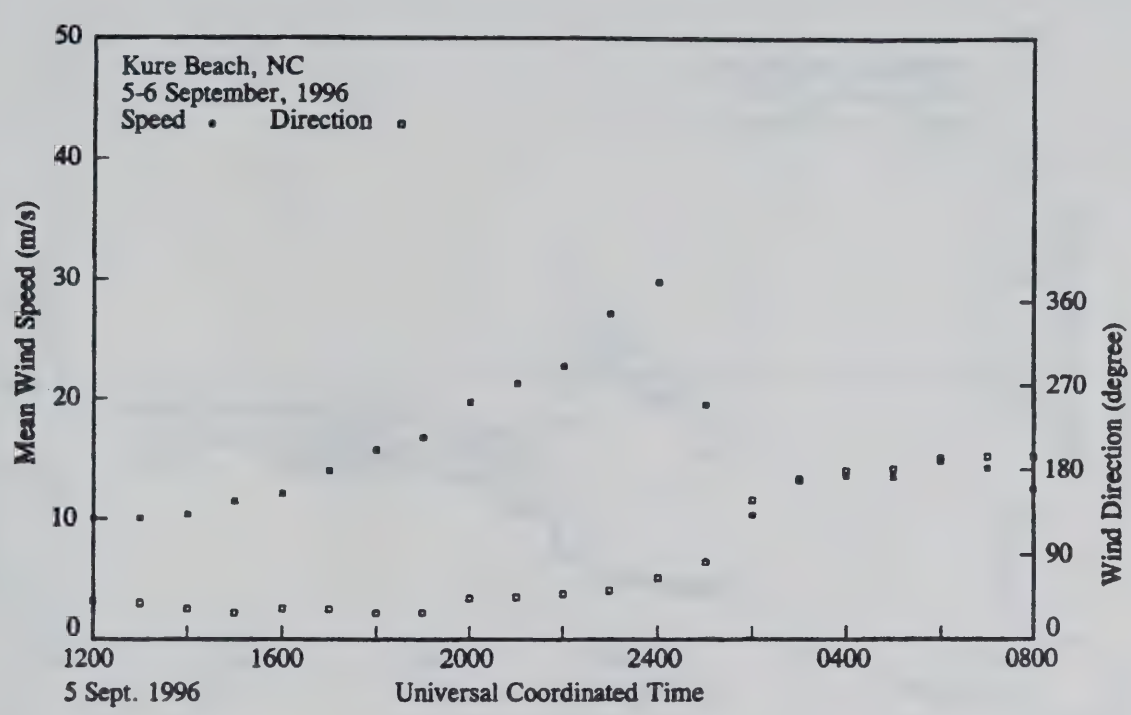

Figure A-9. Record of mean wind speed and direction, Kure Beach, NC.

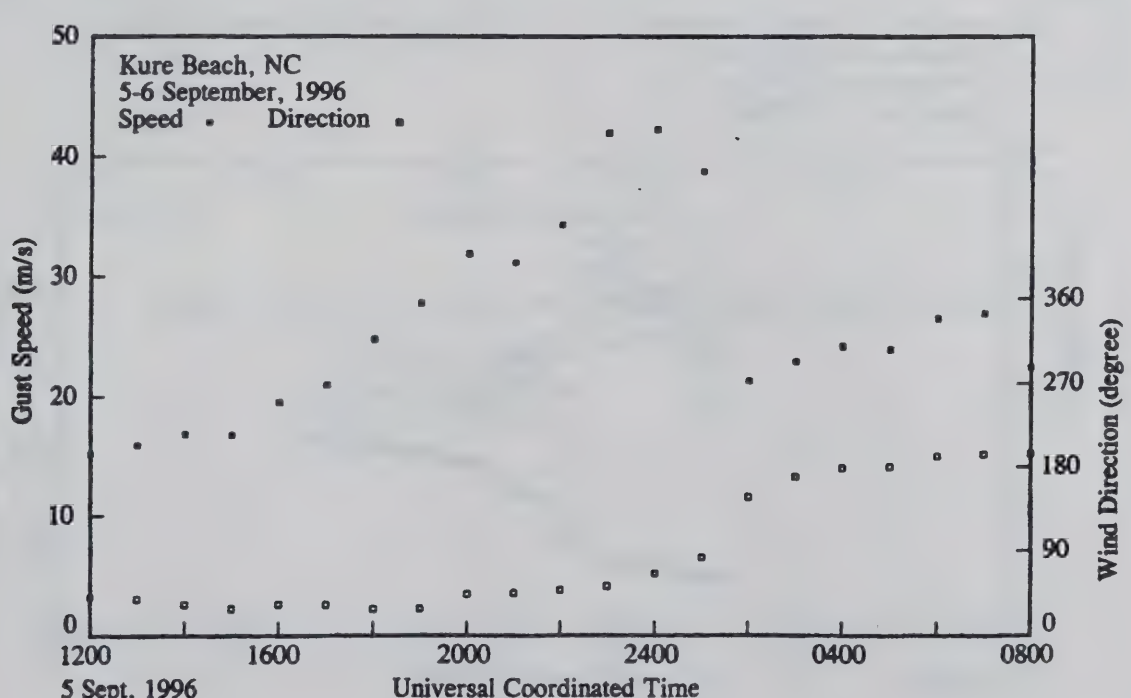

Figure A-10. Record of gust speed and direction, Kure Beach, NC.

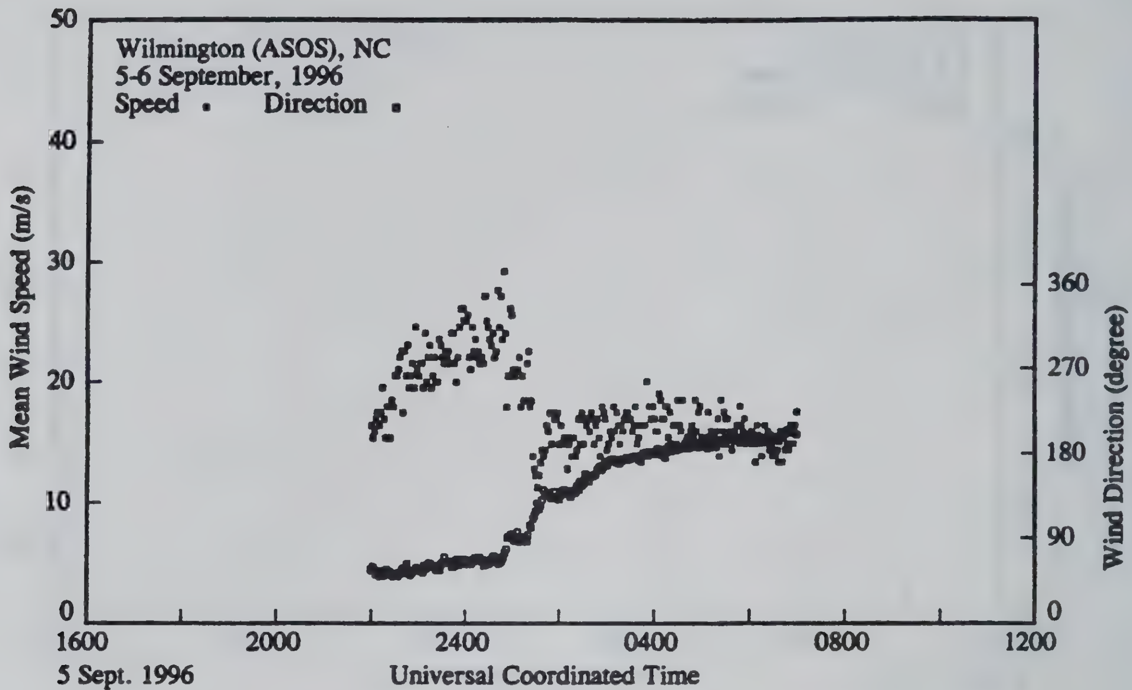

Figure A-11. Record of mean wind speed and direction, Wilmington (ASOS), NC.

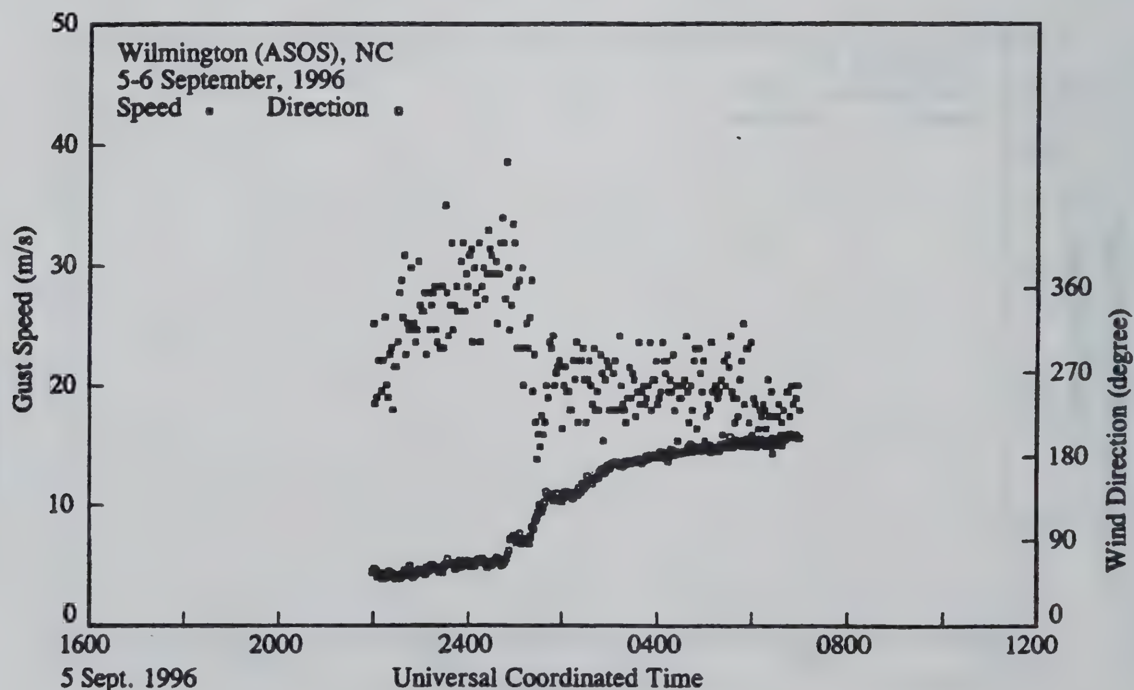

Figure A-12. Record of gust speed and direction, Wilmington (ASOS), NC.

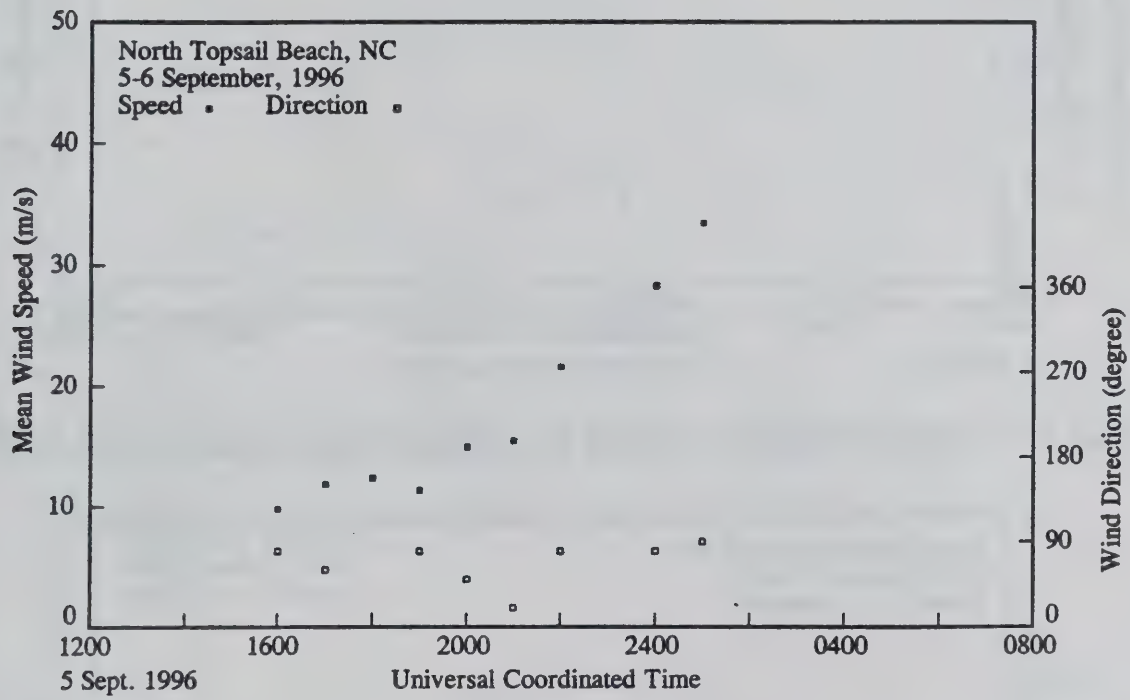

Figure A-13. Record of mean wind speed and direction, North Topsail Beach, NC.

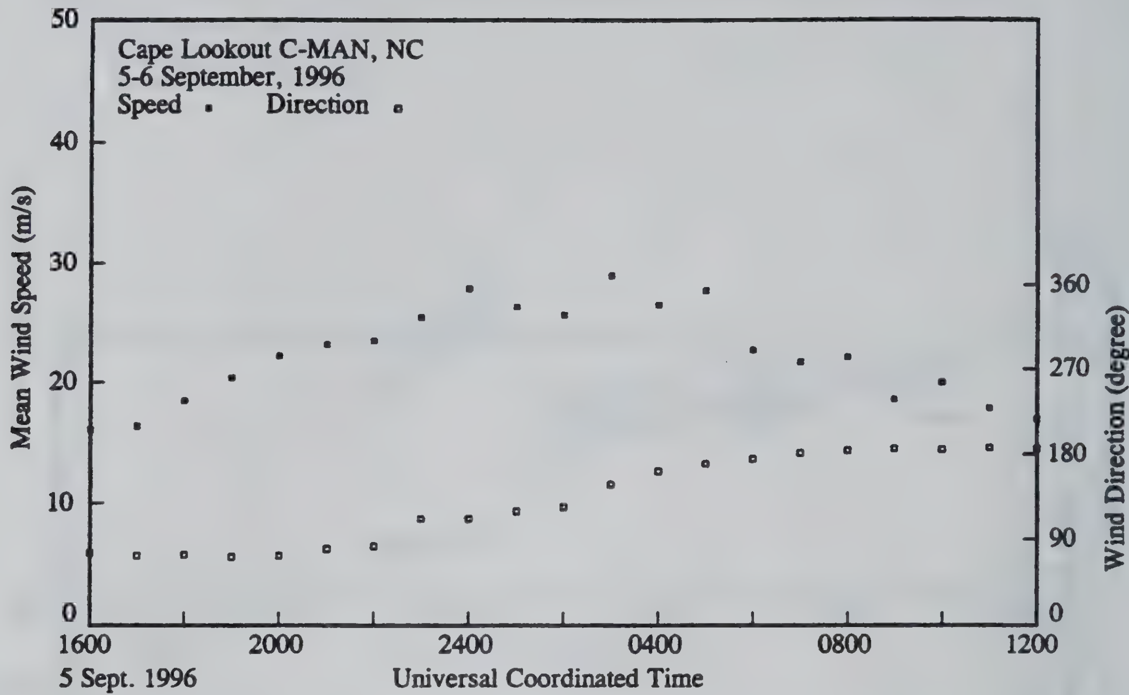

Figure A-14. Record of mean wind speed and direction, Cape Lookout C-MAN, NC.

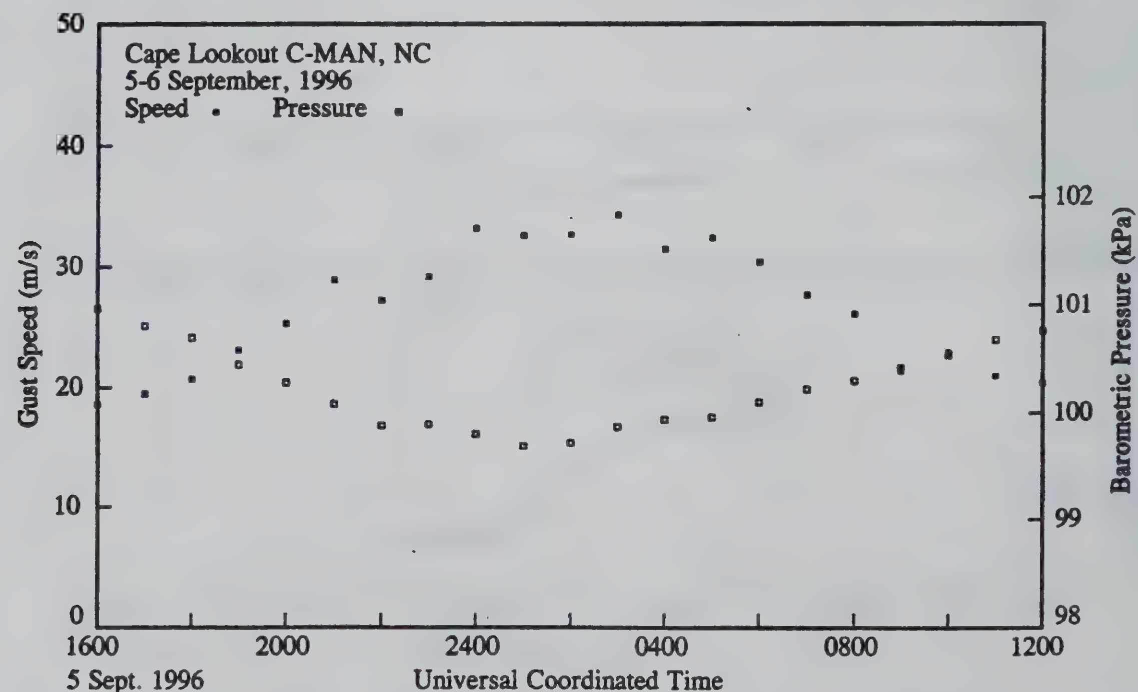

Figure A-15. Record of gust speed and barometric pressure, Cape Lookout C-MAN, NC.

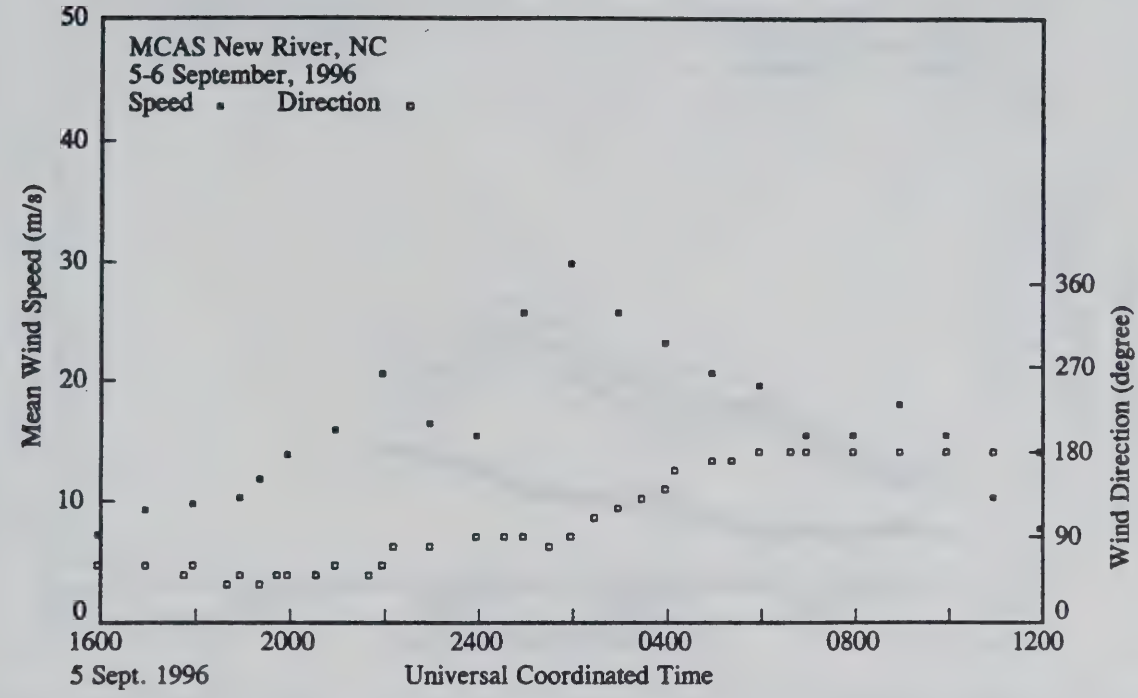

Figure A-16. Record of mean wind speed and direction, MCAS New River, NC.

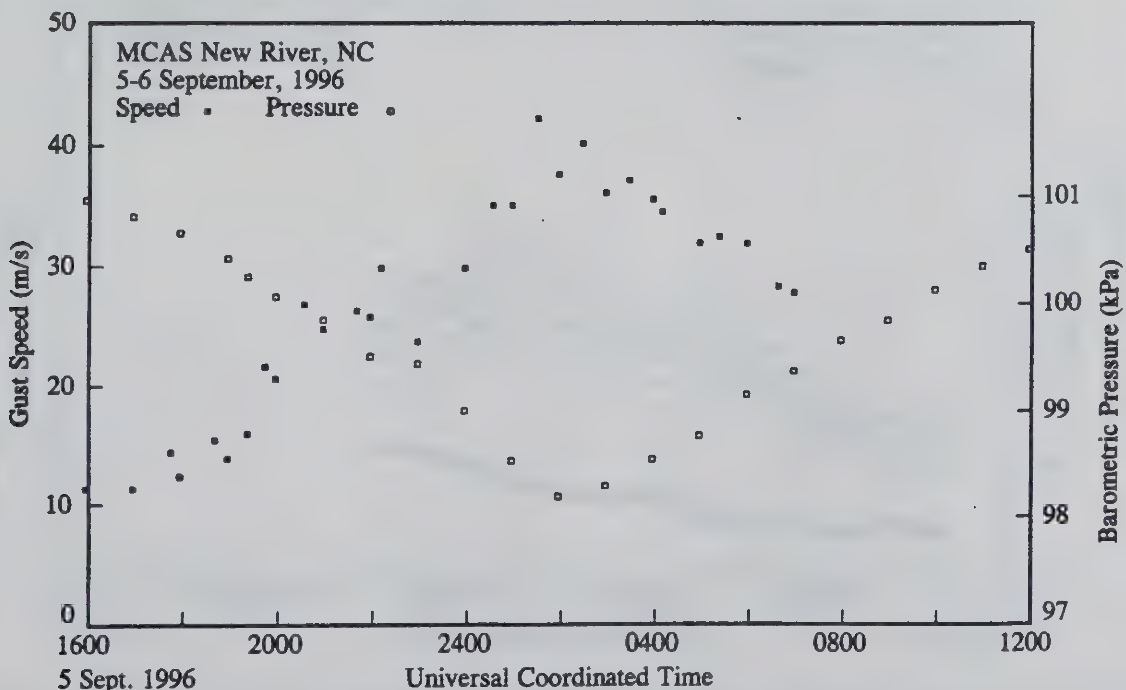

Figure A-17. Record of gust speed and barometric pressure, MCAS New River, NC.

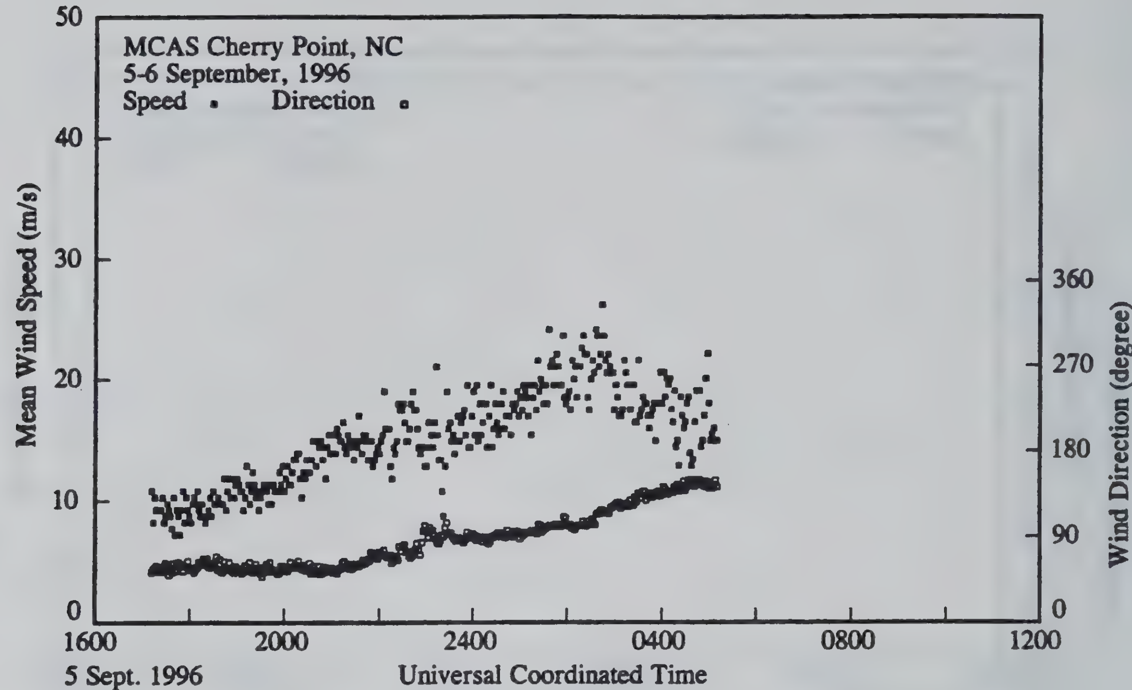

Figure A-18. Record of mean wind speed and direction, MCAS Cherry Point, NC.

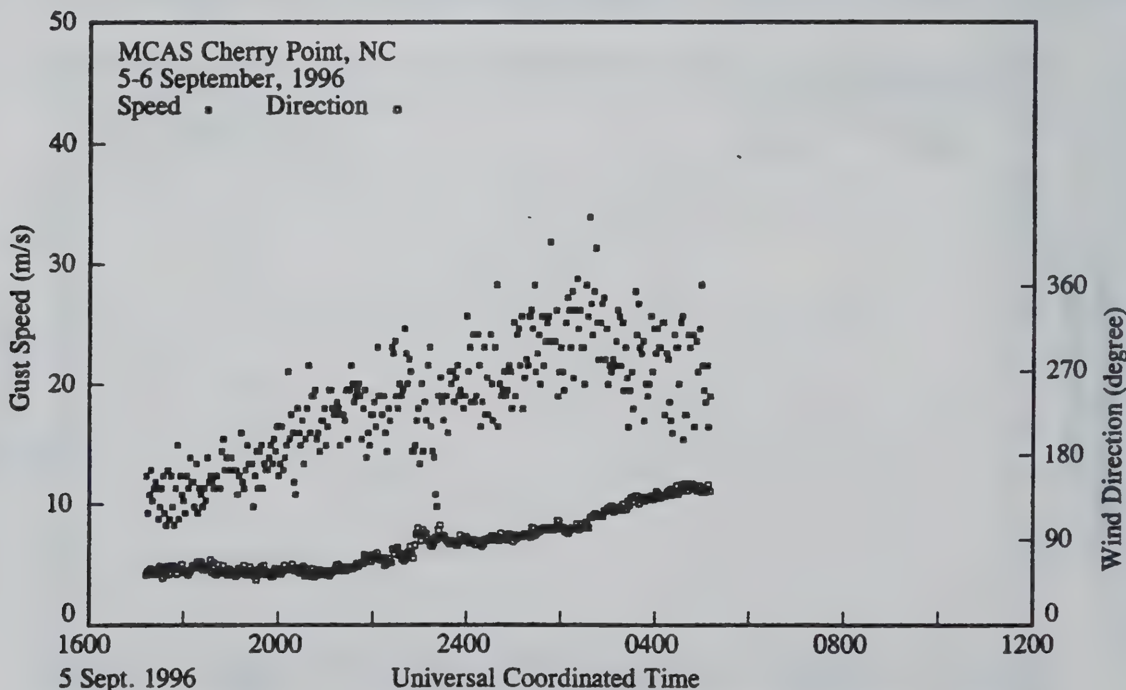

Figure A-19. Record of gust speed and direction, MCAS Cherry Point, NC.

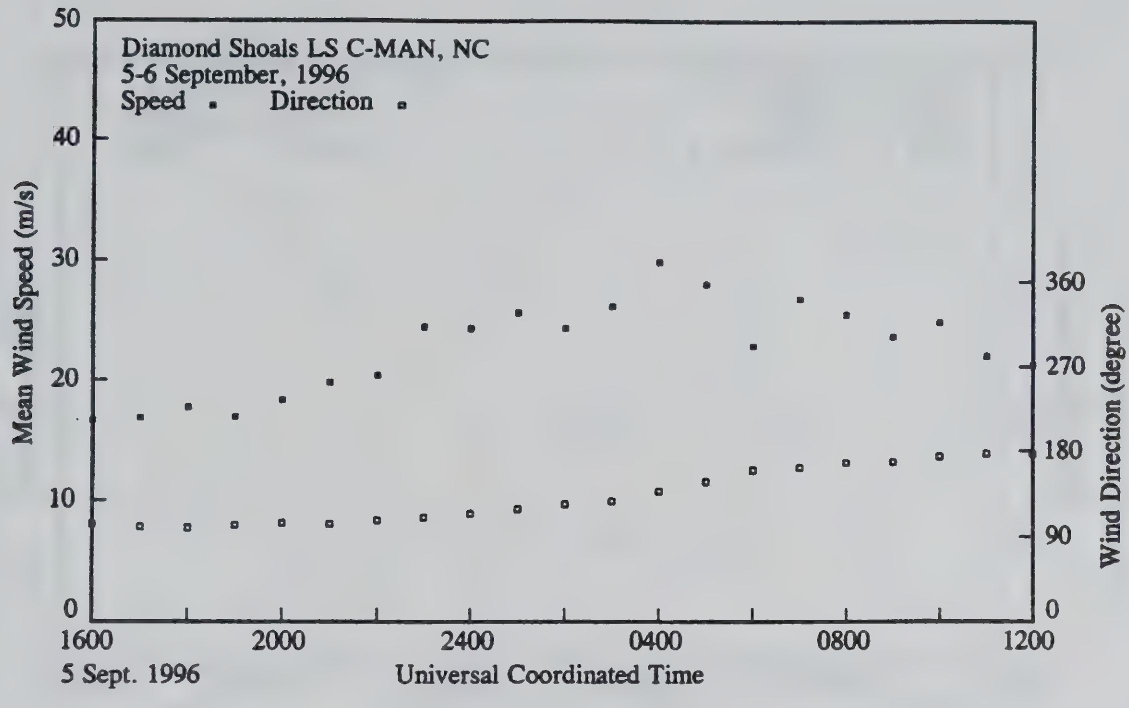

Figure A-20. Record of mean wind speed and direction, Diamond Shoals LS C-MAN, NC.

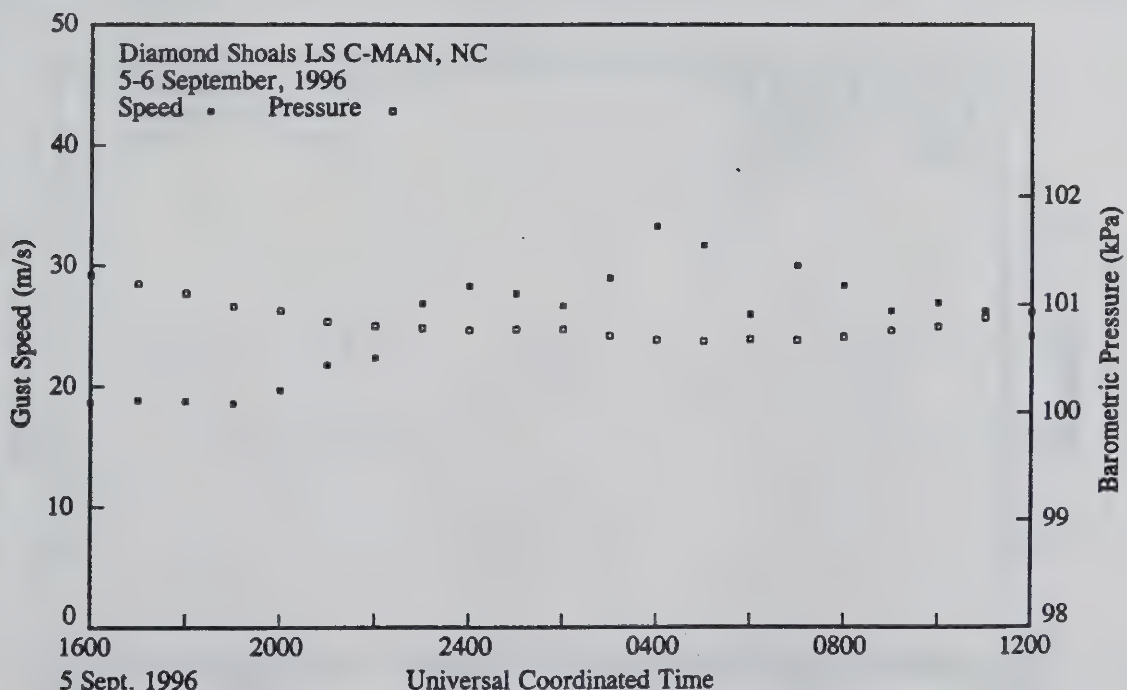

Figure A-21. Record of gust speed and barometric pressure, Diamond Shoals LS C-MAN, NC.

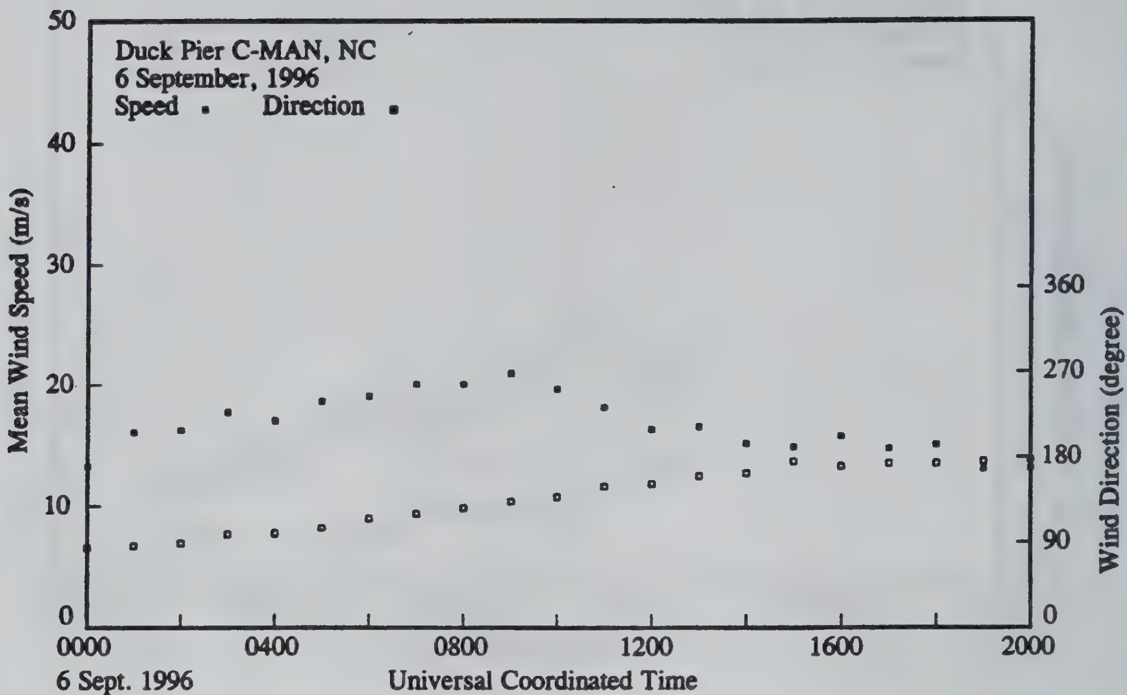

Figure A-22. Record of mean wind speed and direction, Duck Pier C-MAN, NC.

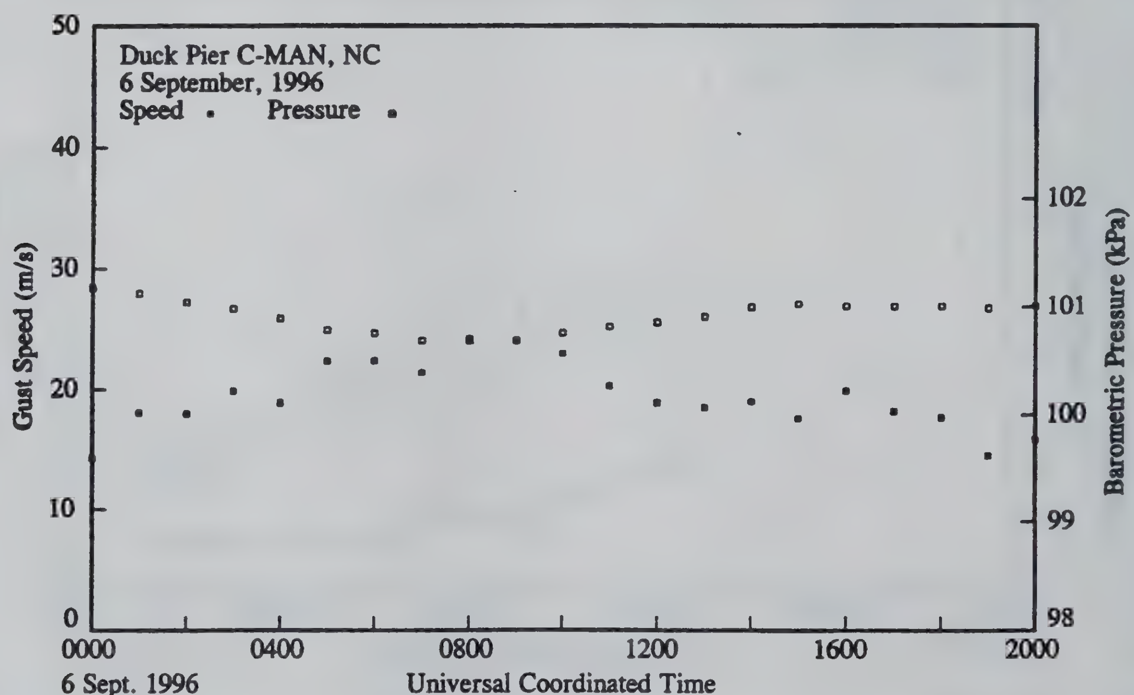

Figure A-23. Record of gust speed and barometric pressure, Duck Pier C-MAN, NC.

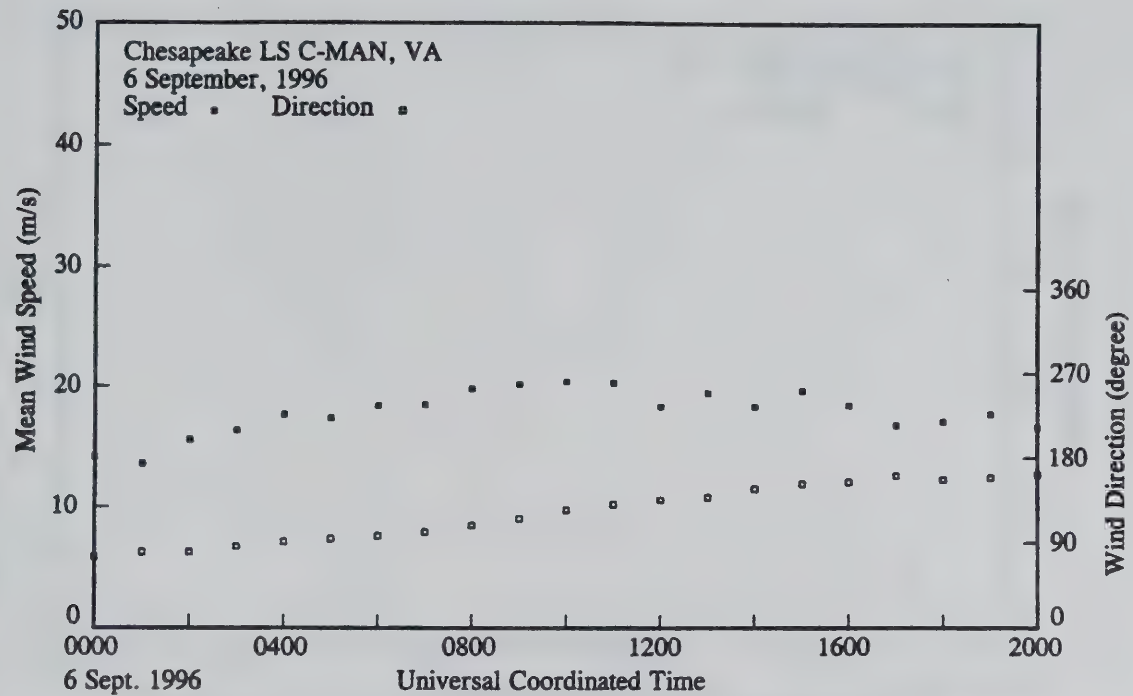

Figure A-24. Record of mean wind speed and direction, Chesapeake LS C-MAN, VA.

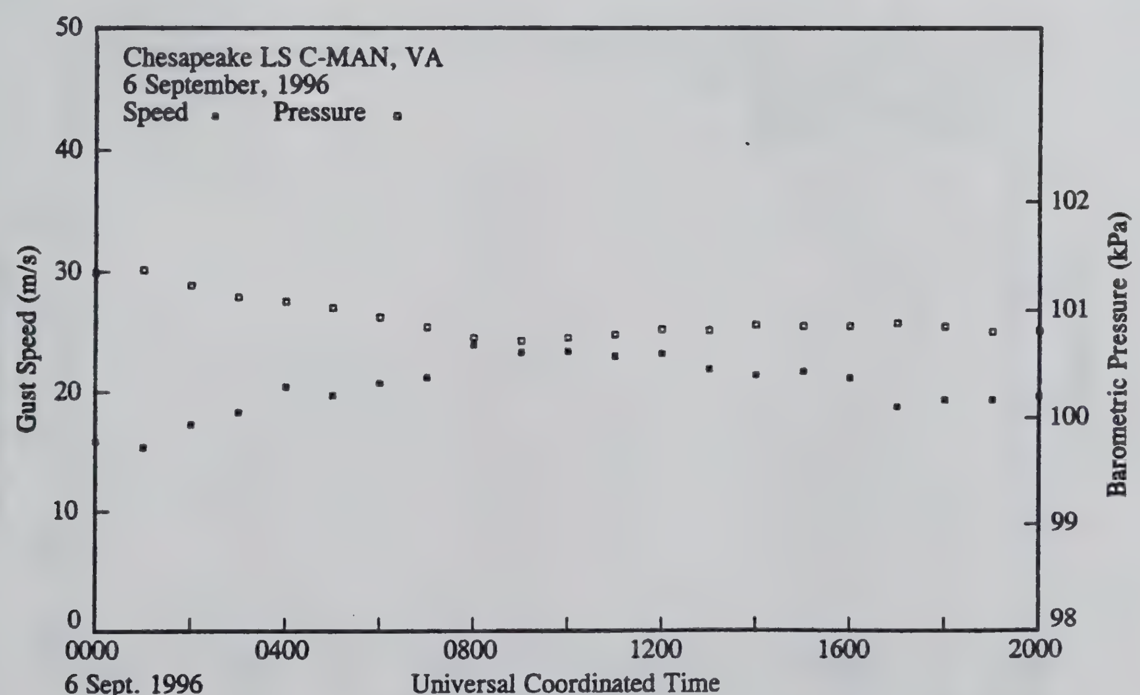

Figure A-25. Record of gust speed and barometric pressure, Chesapeake LS C-MAN, VA.

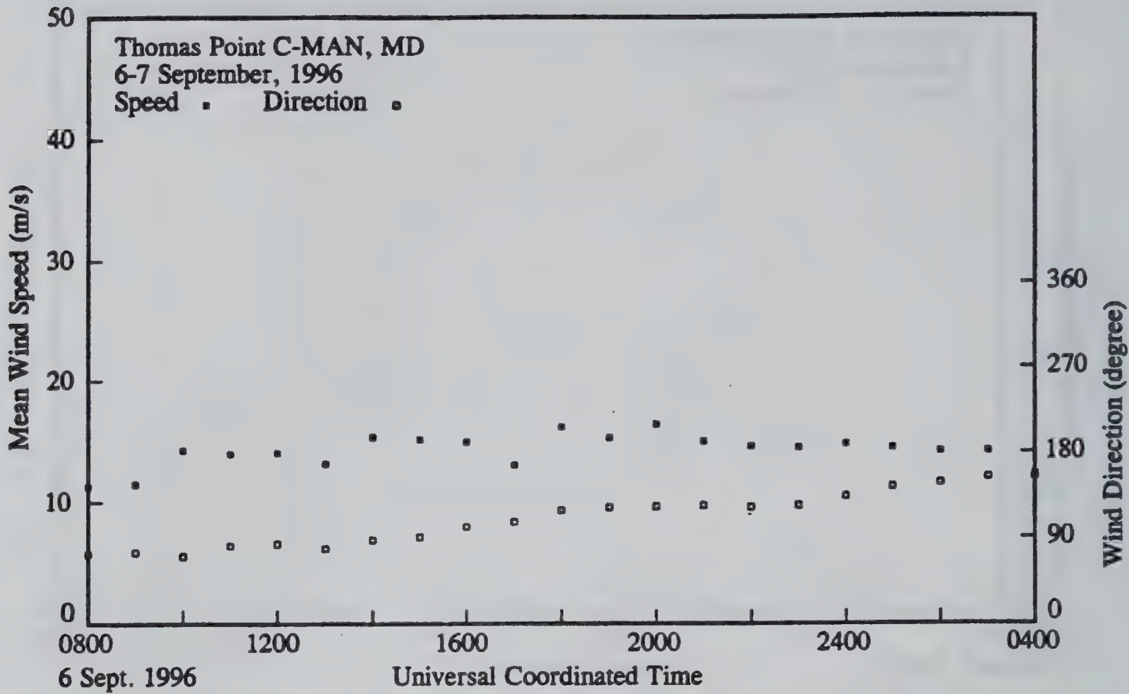

Figure A-26. Record of mean wind speed and direction, Thomas Point C-MAN, MD.

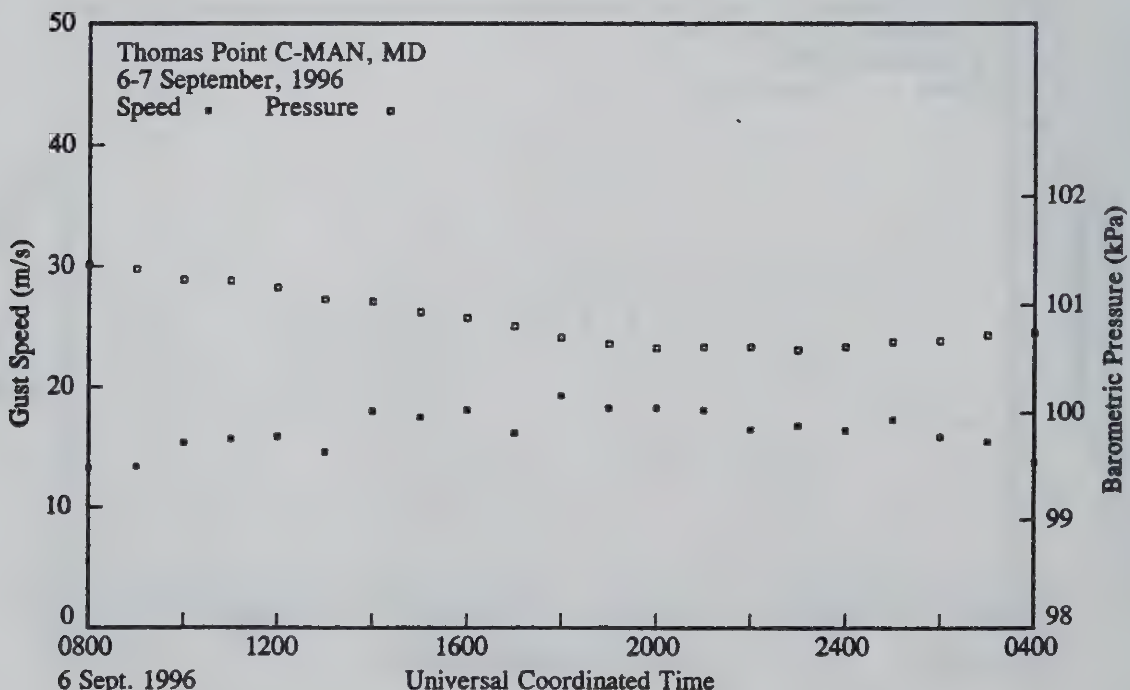

Figure A-27. Record of gust speed and barometric pressure, Thomas Point C-MAN, MD.

APPENDIX B

Adjusted Wind Speeds for Selected Anemometer Sites

Table B-1. Adjusted Sustained Speeds at Selected Sites for Over-Water or Over-Land Exposures.

Station:	Folly Island C-MAN
Coordinates (deg):	32.68 N 79.88 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	12.3 (05/1700 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	15.9 (Est. = 14.9)
Est. Max. Sustained Speed @ 10 m (m/s):	12.9
Surface Roughness Length (m):	0.00032
Station:	Frying Pan Shoals C-MAN
Coordinates (deg):	33.48 N 77.58 W
Anemometer Ht. (m):	44.2
Max. Observed Mean Speed (m/s):	40.6 (05/2100 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	48.4 (Est. = 49.6)
Est. Max. Sustained Speed @ 10 m (m/s):	36.2
Surface Roughness Length (m):	0.0042
Station:	Cape Lookout C-MAN
Coordinates (deg):	34.62 N 76.52 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	28.8 (06/0300 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	34.5 (Est. = 35.9)
Est. Max. Sustained Speed @ 10 m (m/s):	30.4
Surface Roughness Length (m):	0.00268
Station:	Diamond Shoals C-MAN
Coordinates (deg):	35.15 N 75.30 W
Anemometer Ht. (m):	46.6
Max. Observed Mean Speed (m/s):	29.8 (06/0400 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	33.4 (Est. = 35.6)
Est. Max. Sustained Speed @ 10 m (m/s):	26.7
Surface Roughness Length (m):	0.00192
Station:	Duck Pier C-MAN
Coordinates (deg):	36.18 N 75.75 W
Anemometer Ht. (m):	20.4
Max. Observed Mean Speed (m/s):	21.1 (06/0900 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	24.2 (Est. = 25.3)
Est. Max. Sustained Speed @ 10 m (m/s):	20.5
Surface Roughness Length (m):	0.001

Table B-1 (Cont.)

Station:	Chesapeake LS C-MAN
Coordinates (deg):	36.92 N 75.72 W
Anemometer Ht. (m):	43.3
Max. Observed Mean Speed (m/s):	20.6 (06/1000 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	23.7 (Est. = 24.0)
Est. Max. Sustained Speed @ 10 m (m/s):	18.6
Surface Roughness Length (m):	0.0008
Station:	Thomas Point C-MAN
Coordinates (deg):	38.90 N 76.44 W
Anemometer Ht. (m):	18
Max. Observed Mean Speed (m/s):	16.5 (06/2000 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	19.5 (Est. = 19.6)
Est. Max. Sustained Speed @ 10 m (m/s):	16.2
Surface Roughness Length (m):	0.00056
Station:	Data Buoy 41002
Coordinates (deg):	32.27 N 75.19 W
Anemometer Ht. (m):	5
Max. Observed Mean Speed (m/s):	19.0 (05/1700 UTC)
Averaging Time (minutes):	8
Observed Pk. Gust (m/s):	25.7 (Est. = 25.6)
Est. Max. Sustained Speed @ 10 m (m/s):	22.9
Surface Roughness Length (m):	0.0013
Station:	Data Buoy 41004
Coordinates (deg):	32.5 N 79.1 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	24.2 (Failed 05/1900 UTC)
Averaging Time (minutes):	8
Observed Pk. Gust (m/s):	32.4 (Est. = 32.1)
Est. Max. Sustained Speed @ 10 m (m/s):	27.3
Surface Roughness Length (m):	0.00203
Station:	Kure Beach
Coordinates (deg):	34.00 N 77.91 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	29.8 (06/0000 UTC)
Averaging Time (minutes):	60
Observed Pk. Gust (m/s):	42.2 (Est. = 42.8)
Est. Max. Sustained Speed @ 10 m (m/s):	35.8
Surface Roughness Length (m):	0.01, x = 500 m (land) + 0.00407 (water)

Table B-1 (Cont.)

Station:	Wilmington (ASOS)
Coordinates (deg):	34.27 N 77.91 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	29.8 (06/0049 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	38.6 (Est. = 38.5)
Est. Max. Sustained Speed @ 10 m (m/s):	30.7
Surface Roughness Length (m):	0.03 (Reference)
	0.01, x = 800 m (land)
	+ 0.10, x = 14000 m (land)
	+ 0.00391 (water)
Station:	North Topsail Beach
Coordinates (deg):	34.52 N 77.36 W
Anemometer Ht. (m):	12.2
Max. Observed Mean Speed (m/s):	33.4 (Failed 06/0100 UTC)
Averaging Time (minutes):	1
Observed Pk. Gust (m/s):	-- (Est. = 39.7)
Est. Max. Sustained Speed @ 10 m (m/s):	33.6
Surface Roughness Length (m):	0.10, x = 100 m (land)
	+ 0.00346 (water)
Station:	MCAS New River (ASOS)
Coordinates (deg):	34.71 N 77.44 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	29.8 (06/0156 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	42.2 (Est. = 38.7)
Est. Max. Sustained Speed @ 10 m (m/s):	32.0
Surface Roughness Length (m):	0.03 (Reference)
	0.01, x = 1300 m (land)
	+ 0.00304, x = 4000 m (water)
	+ 0.10 (land)
Station:	MCAS Cherry Point (ASOS)
Coordinates (deg):	34.90 N 76.88 W
Anemometer Ht. (m):	10
Max. Observed Mean Speed (m/s):	26.2 (06/0244 UTC)
Averaging Time (minutes):	2
Observed Pk. Gust (m/s):	34.0 (Est. = 35.0)
Est. Max. Sustained Speed @ 10 m (m/s):	28.1
Surface Roughness Length (m):	0.03 (Reference)
	0.03, x = 2,000 m (land)
	+ 0.15 (land)